PATAPSCO RIVER SHAD AND HERRING RESTORATION

2014 Progress Report
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Production, Marking and Stocking

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Background

The Patapsco River shad and herring restoration project is part of a compensatory mitigation package designed around the Masonville Project. The Masonville Project is located in the heart of Baltimore Harbor, and at the center of the project is the Dredged Material Containment Facility (DMCF). The Masonville Cove Environmental Education Center and a 22-hectare Conservation Area were constructed adjacent to the DMCF in 2009. As a component of the DMCF project, the Maryland Port Administration (MPA) was required to develop a compensatory mitigation package to offset impacts associated with filling approximately 130 acres (53 hectares) of open water in the Patapsco River; a major tributary to the Chesapeake Bay. The Patapsco River restoration project will hopefully add fishing opportunities for the local community by re-establishing anadromous species such as American and Hickory Shad to the Patapsco River. Under this mitigation package, Patapsco River shad and herring restoration was selected, and is the subject of this monitoring report.

The MPA has funded the Maryland Department of Natural Resources (DNR) to lead the Patapsco River shad and herring restoration effort. DNR is responsible for marking and stocking Alewife Herring, Blueback Herring, Hickory Shad and American Shad described in section one of this report. DNR contracted the U.S. Fish & Wildlife Service, Maryland Fishery Resources Office (MFRO) to perform monitoring activities of stocking efforts including field sampling and collections, laboratory sample preparation and interpretation, data analysis, and report writing for sections two and three.

American Shad (*Alosa sapidissima*) was once the most important commercial and recreational fish species in the Chesapeake Bay. In response to severe population declines from 1900 to the 1970s, Maryland closed its fishery in 1980. Various factors that contributed to this decline include over-fishing, stream blockages that impeded upstream fish movement, and poor water quality (Hildebrand and Schroeder 1928). The remaining severely depressed native adult stocks do not presently utilize most Chesapeake Bay tributaries, including the Patapsco River (Klauda et al. 1991), which historically supported spawning stocks (Mansueti and Kolb 1953). Improvements in water quality, a sustained fishing moratorium, and removal of many stream blockages has reopened potential alosine spawning habitat and allowed American Shad to return to many

Chesapeake Bay tributaries. Since shad show evidence of density dependent spawning behavior, self- sustaining shad populations are not likely to return to these tributaries without hatchery supplementation. Development of spawning, culture, marking and stocking techniques could reintroduce spawning populations of American Shad to this target tributary. Funding obtained through Sport Fish Restoration Act F-57-R has supported a Maryland Department of Natural Resources (MDNR) shad restoration program since 1999 in other Maryland tributaries to the Chesapeake Bay. Substantial progress in restoring American Shad populations was previously documented in the Patuxent River and Choptank River. Techniques and strategies developed in that program could be applied to Patapsco River restoration efforts.

Hickory Shad (*Alosa mediocris*) were historically abundant in many Chesapeake Bay tributaries (O'Dell et al. 1975, 1978). Recently, some upper Bay tributaries have experienced a mild resurgence in Hickory Shad runs. This increase in Hickory Shad brood stock provides the opportunity to culture and stock this species. Few studies have investigated Hickory Shad and little is known about their life history in the Chesapeake Bay. Previous work conducted under F-57-R funding has yielded new Hickory Shad spawning strategy and life history information (Richardson et al, 2007). Many Bay tributaries had historical Hickory Shad runs equal to or greater than that of American Shad. It could be useful to develop natural spawn, culture and marking techniques to attempt restoration of this species to historical abundance levels. These techniques have been refined during ongoing restoration projects and can be applied to the Patapsco River.

River herring is the collective term for Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*). These species experienced recent declines throughout the Chesapeake Bay region and other Atlantic Coast populations. Dams have blocked much of the Patapsco River herring spawning habitat for more than a century. Recent fish passage implementation has reopened historical spawning habitat and reintroduction through hatchery inputs could have positive impacts to these populations. The proposed 2016 removal of Bloede Dam will open the river at its most downstream impoundment.

MDNR restoration work thus far indicates that self-sustaining shad restoration will likely occur over a period of decades, rather than years. The Patuxent River was stocked at a high level from 1994-2009 and it has only been during the last several years that wild juvenile abundance has increased. Herring restoration would likely occur in a shorter time frame due to their younger age at maturity. The long time frame for American Shad restoration limits potential adult assessment activities considering the three-year funding commitment for the Masonville project. However, stocking larvae and juveniles for a period of three years at a high level should result in the presence of Patapsco River spawning adults in five to six years. Hickory Shad adults should return to the Patapsco River primarily at age three. Limited assessment of Hickory Shad adults will be conducted in the third year of the Masonville mitigation project although some Hickory Shad adults could return at age two. Results for herring stocking should appear more quickly in adult sampling and some indication of success could be apparent within the sampling timeframe. Larval and juvenile sampling for all target species will provide substantial information on the current populations and the impacts of stocking hatchery-cultured fish.

Objective

The overall objective for this proposed scope of work is to introduce juvenile American Shad, Hickory Shad and herring populations to the Patapsco River. Stocking larval and juvenile hatchery-origin fish should produce adult stock that will return to spawn upon maturity. The depressed native stocks do not optimally utilize these tributaries. This tributary has historically supported spawning runs.

Expected Results and Benefits

Hatchery inputs are intended to create adult spawning stock that could produce self-sustaining populations in the target tributary. These hatchery fish have tremendous value for stock assessment purposes at the larval, juvenile and adult life stages since all stocked fish receive an otolith mark. Natural spawn and strip spawn culture techniques allow for the production of large numbers of larval and juvenile shad and herring for stocking and assessment efforts.

Upper Bay shad populations currently support popular catch and release recreational fishing. Restoring shad and herring stocks to other tributaries that historically supported runs will increase fishing opportunities for anglers. Recreational fishing targeting Hickory Shad and American Shad occurs in the Patuxent River and Choptank River, primarily due to ongoing restoration efforts.

Approach

The project consists of three sub-projects:

1. *Produce, mark and stock cultured American Shad, Hickory Shad and herring in the Patapsco River.*
2. *Monitor the abundance and mortality rates of larval and juvenile shad and herring using marked hatchery-produced fish. (Appendix 1)*
3. *Assess the contribution of hatchery fish to the adult Hickory Shad and herring spawning population. (Appendix 1)*

Location

Restoration efforts will focus on the Patapsco River (Figure 1). The Patapsco River watershed is heavily impacted by urban, commercial and industrial development but has been the subject of numerous mitigation efforts due to its designation as a targeted watershed (i.e. sewage treatment upgrades, fish passage, and dam removal).

Sub-project 1.

"Produce, mark and stock cultured American Shad, Hickory Shad, Alewife, *and* Blueback Herring *in the Patapsco River."*

Broodstock collection, production, culture, and marking differ between species, and each will be discussed separately.

American Shad

In 2014, MDNR staff produced, marked, and stocked American Shad larvae and juveniles. American Shad production needs were met by strip spawning brood fish from the Potomac River (Figure 2). American Shad larvae and early juveniles were stocked in the Patapsco River (Figure 1). Larval fish were stocked into the river immediately after being marked with a day 3, 6, 10 oxytetracycline (OTC) mark. Early juvenile fish were marked with a day 3, 6 OTC mark, placed in hatchery ponds for an additional grow out period, and stocked in the river at approximately 30 days of age.

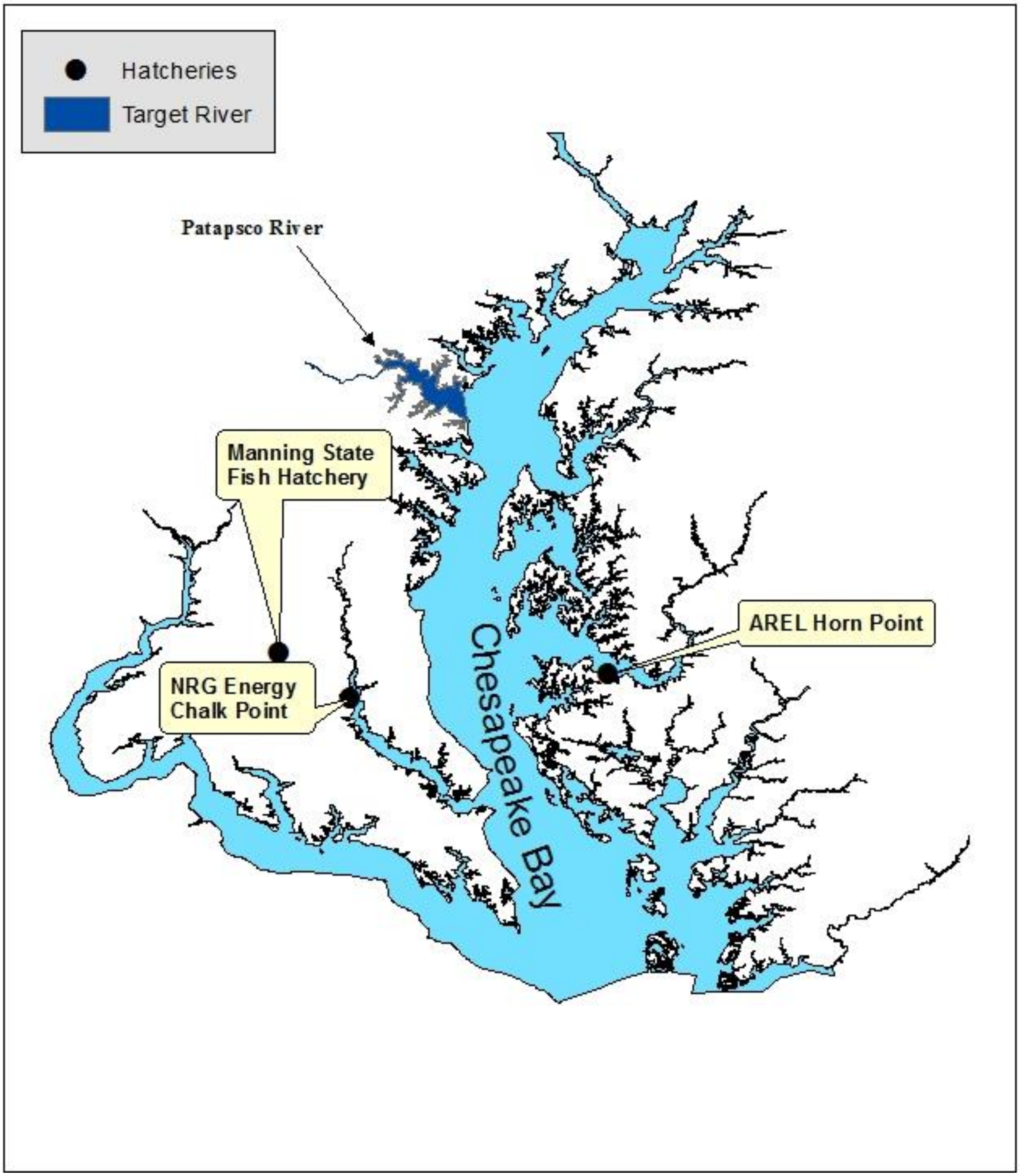

Figure 1. *2014 target tributary and culture sites for Maryland Department of Natural Resources shad restoration project. NRG Energy is a power company that cultures fish for the restoration effort. The Horn Point Aquaculture Restoration and Ecology Laboratory, is a University of Maryland Center for Environmental Science facility that supplies culture ponds for the restoration effort.*

Materials and Methods

Brood Stock Collection

American Shad were originally produced utilizing tank natural-spawn culture methods developed by the project. Declining production success of American Shad from tank spawn operations dictated that an additional source of larvae be developed.

In 2001, the decision was made to collect ripe fish on the spawning grounds and manually strip eggs and milt from mature brood fish. The Potomac River was chosen as the brood source due to its healthy American Shad spawning population. The project hired a commercial fisherman to assist in egg collections that year. In 2002, it was determined that project personnel could perform these collections more efficiently and economically and this method is still utilized. Different areas along the Potomac River were evaluated for their ability to concentrate American Shad. The channel in front of Fort Belvoir concentrates the greatest quantity of American Shad (Figure 2). The collections were carried out using gill nets aboard a 7.0 m flat-bottom, center console skiff equipped with an outboard motor.

Weather and temperature conditions in late March and early April greatly influence the timing of American Shad spawning on the Potomac River. It is essential to begin sampling in early April to ensure that collections occur during peak shad spawn. Sampling begins when water temperatures are 14 to 16°C. In early April, the majority of captured American Shad females are gravid, but not yet ripe for egg collection. In early May, most captured females are ripe and appropriate for egg collection. Spent females also begin to appear at this time. Gradually, the composition shifts so that most captured females are spent. Broodstock collections conclude after this shift to a majority of spent females, since the contribution to egg production is low.

Gill nets were set parallel to the channel edge at depths varying between approximately 7.0 and 18.0 m. The time of net set depended exclusively on tide. Nets were ideally set at the beginning of slack tide. Past efforts indicated that setting nets at or near slack tide had a tendency to collect more shad. Nets were set for approximately one hour. Because American Shad are predisposed to spawn near, or just after sundown

(Mansueti and Kolb 1953), nets were set during the period from 1530 to 2130. Collecting shad before or after this six-hour window was deemed ineffective.

Catch per unit effort (CPUE) is used as an index of relative abundance. Gill net CPUE is established by dividing the number of fish caught per net, by the square footage of net fished per hour of soak time. A hand tally counter (tallycounterstore.com) is used to keep accurate count of all American Shad caught from each net. Although trends in overall American Shad catch rates can be monitored using CPUE (Figure 3), the use of non-standardized gear through time makes it difficult to establish accurate relative abundance estimates over time. CPUE is an accurate tool to evaluate the most efficient gear to collect American Shad. Gill net CPUE differs greatly based on the net construction (monofilament vs. multifilament), net mesh size, and net depth.

Two different nets were evaluated to study catch efficiency using different net mesh size and net depth. Gill nets with smaller mesh size have the tendency to catch smaller fish while nets with larger mesh sizes have a tendency to catch larger fish. On average, four nets were set per night, depending on weather conditions and boat traffic. In 2014, MDNR staff typically fished two sizes (127 mm stretch, 133 mm stretch) of floating gill nets a majority (97%) of the time. A smaller stretch mesh net (117.5mm) was fished on 14 and 16 May to try to collect more males. This net collected only 4.1% of the total males collected during the season. The two net sizes fished throughout the collection season exhibited similar catch efficiency (Figure 4).

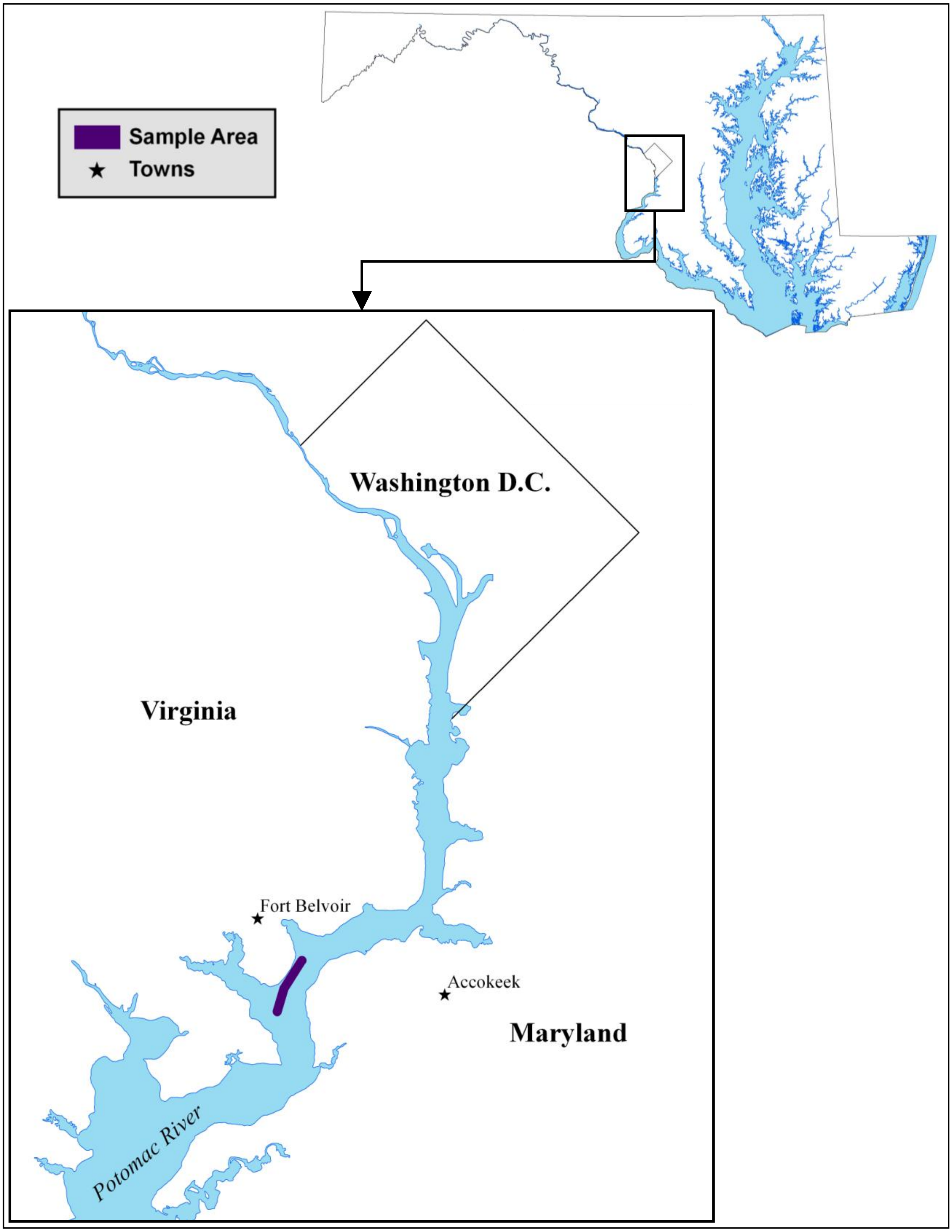

Figure 2. *2014 Maryland Department of Natural Resources American Shad brood stock collection site on the Potomac River.*

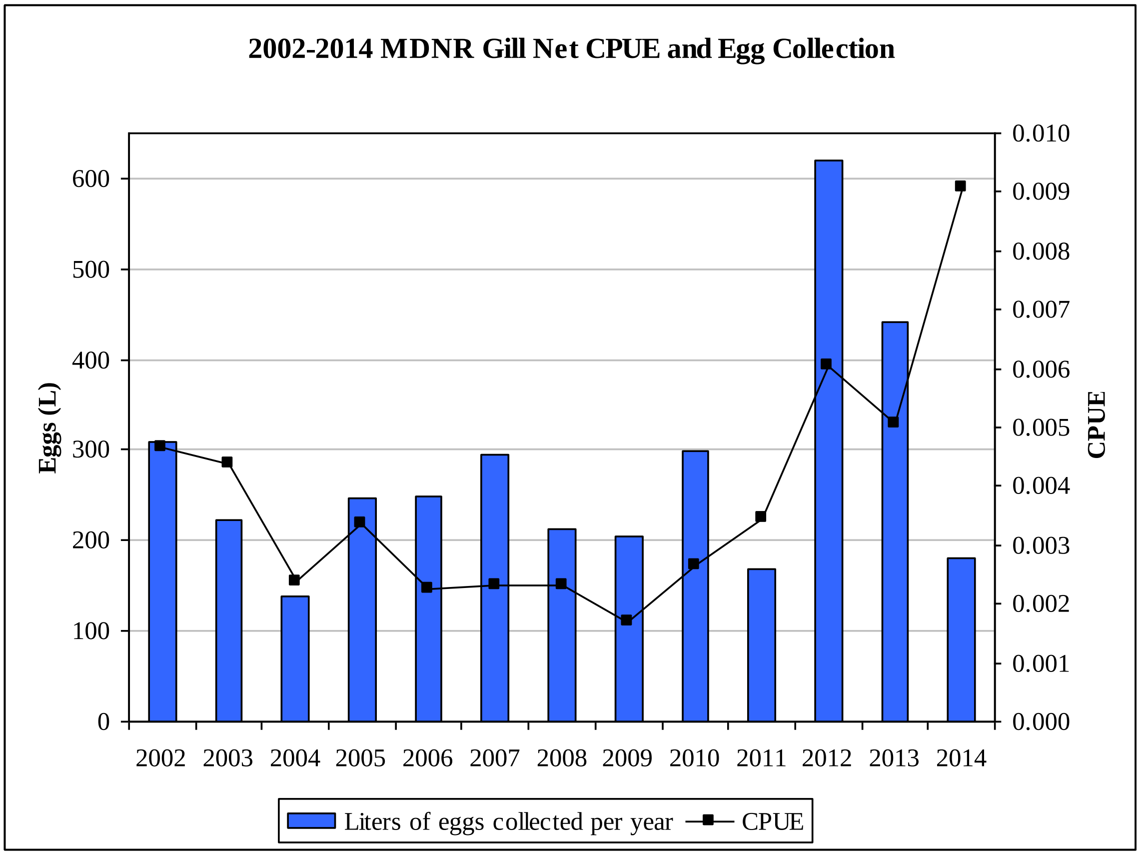

Figure 3. *2002-2014 Maryland Department of Natural Resources gill net CPUE and egg collection of American Shad on the Potomac River.*

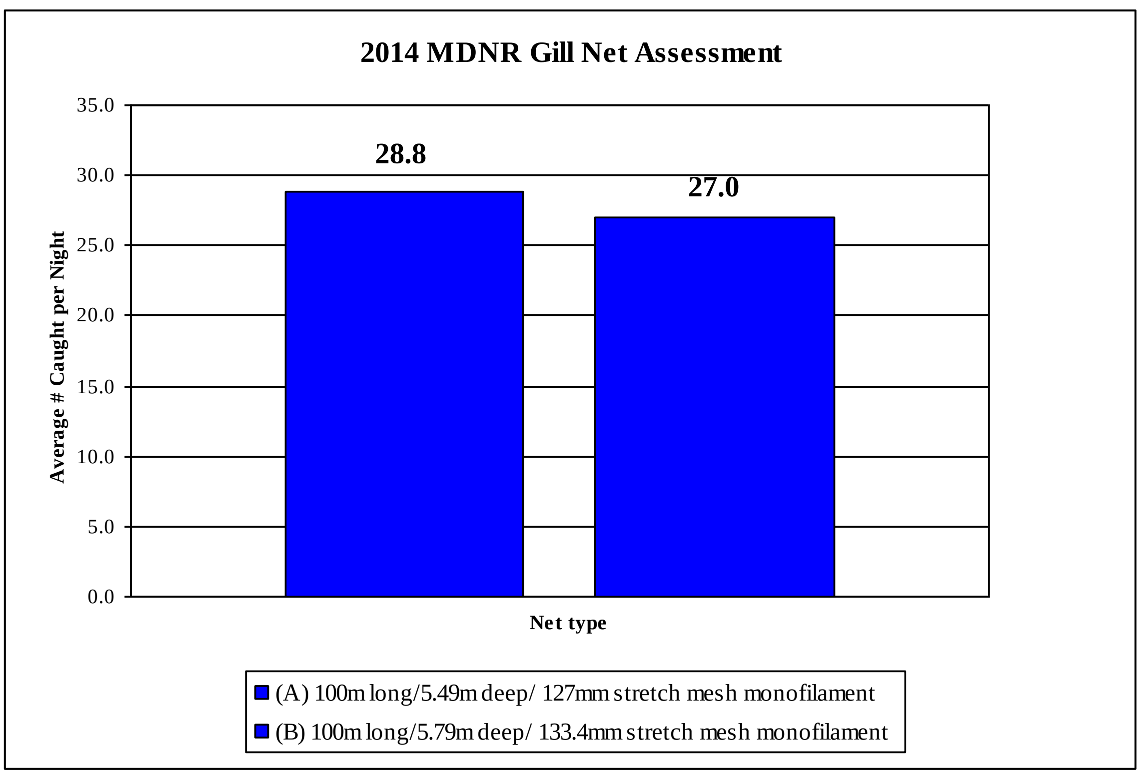

Figure 4. *2014 Maryland Department of Natural Resources American Shad gill net assessment on the Potomac River.*

Egg Fertilization and Culture

Egg fertilization was conducted aboard a flat deck fiberglass skiff on the Potomac River. Ripe females and males were removed from gill nets and placed into separate water-filled holding tubs on the boat. Eggs were manually stripped into clean, dry bowls and milt was deposited over the eggs using the dry method described by Howey (1985). River water was then added to activate the sperm and allowed to sit for 10 minutes. Fertilized eggs were rinsed to be cleaned of any blood or ovarian tissue and carefully poured into a floating modified Tupperware™ egg box for at least one hour to water harden. This minimized egg damage during transport to the hatchery. The egg box was modified to allow water to enter and exit without losing eggs. The egg boxes were placed in a larger water container on the deck of the boat and transported to Manning State Fish Hatchery (Brandywine, Maryland) for culture (Figure 1).Pure oxygen was added during transport.

Eggs were placed in modified McDonald hatching jars supplied by approximately 2.0 L/min water flow. Prophylactic treatments of formalin were administered in the morning and afternoon to control fungi. Eggs were exposed to a 600:1 treatment of formalin for approximately 17 minutes. Eggs were volumetrically measured at the hatchery and percent fertilization was determined 24 hours post-fertilization.

American Shad eggs began hatching at six days post-fertilization. In order to stimulate a simultaneous hatch, jars were removed from the egg bank, placed outdoors in sunlight for ten minutes and stirred occasionally. The increased temperature, lower oxygen content, concentrated hormonal influence and agitation stimulated simultaneous hatching. Jars were then placed around 1.5 m circular, flow-through larval tanks. Water was supplied at approximately 2.0 L/min. Larvae flowed into circular culture tanks after hatch.

Food was introduced to American Shad at day three. American Shad larvae were fed live brine shrimp *Artemia sp*. (www.brineshrimpdirect.com) and 100µm AP100 larval fish food (Zeigler Bros, Gardners, PA) three times daily during daylight hours.

Prior to stocking, larvae were enumerated using a volumetric direct proportion procedure in which a columnar sample of water was collected with a 25.0 mm diameter PVC tube at random locations in the larval tank. Larvae were enumerated in this sample and the total number of larvae in the tank was estimated by extrapolation to the total tank volume. In addition to this enumeration method, eggs were volumetrically measured and counted while performing the fertilization procedure.

Marking

All fish stocked into the target tributary were given an OTC mark through larval immersion. OTC marking is a valuable assessment tool to determine hatchery origin, larval survival, juvenile abundance and mortality estimates. Larval marks were produced by immersion in a 300 ppm buffered OTC bath for six hours. Dissolved oxygen (D.O.) content was monitored and regulated (>5.0 ppm) by a carbon air stone connected to a liquid oxygen delivery system. All water used at Manning Hatchery for OTC marking was softened before use (Culligan ion exchange system). Reliable marking can only take place in water with hardness below 20 mg/L. Water hardness at Manning Hatchery routinely exceeds 200 mg/L. Twenty-five samples analyzed from each group of OTC-marked fish indicated that all stocked fish were successfully marked. Marks were verified by viewing larval otoliths with an ultraviolet (UV) microscope (Zeiss Axioskop). Beginning in 2009, a three-year rotating, year-specific mark for larval stocked American Shad was implemented. This procedure will validate current shad ageing protocols for adult, hatchery-origin American Shad collected. The rotating marks for larval stocked American Shad were: 2009 (day 3), 2010 (day 3, 9), 2011 (day 3, 6, 10), 2012 (day 3) 2013 (day 3, 9) and (day 3, 6, 10) in 2014. This research protocol was recommended by the Atlantic States Marine Fisheries Commission American Shad and River Herring Technical Committee (ASMFC). Larvae designated for early juvenile stocking were given a day 3, 6 OTC mark.

Larval Stocking

In 2014, fish intended for larval stocking received a larval immersion mark at days three, six and ten post-hatch. Stocking was accomplished by placing OTC-marked larvae into boxes originally designed for shipping tropical fish. These containers consisted of an outer shell cardboard box, an inner insulating foam box, a black plastic trash bag to reduce the stress of bright sunlight and a double thickness plastic fish bag. Larval culture tanks were drawn down to crowd the fish. Larvae were scooped out of the tanks using modified milk jugs and placed in the shipping bags/boxes, which were supplemented with approximately 1.0 ppt salt to mitigate stress. Each bag was filled with pure oxygen and sealed with electrician's tape. Boxes were driven to the Patapsco River 100 meters upstream of the Rt. 648 Bridge (Figure 1 and Figure 6). The bags were placed in the water long enough to temperature acclimate. Bags were then opened and river water was slowly introduced to further acclimate larvae to river water conditions. Bags were then emptied into flowing water to minimize predation.

Early Juvenile Stocking

Fish intended for early juvenile stocking received immersion marks at day three and six post-hatch. After the second mark was administered, larvae were stocked into hatchery ponds for approximately thirty days. Manning Hatchery, NRG Energy, and the University of Maryland Center for Environmental Science Aquaculture and Restoration Ecology Laboratory (AREL) Horn Point campus in Cambridge, MD provide grow out ponds to culture fish for the restoration effort (Figure 1). The decision to take juveniles out of the pond was based on zooplankton composition, quality and density. Food availability was evaluated with a plankton net. Early juveniles were removed from culture ponds when food availability declined.

Juvenile fish tend to stress easily and direct netting from hatchery ponds into transport tanks is not recommended. Juvenile fish were concentrated with a seine net 61.0 meters long, 3.1 meters deep, with 6.4mm stretch mesh and bucketed with pond water into the transport tank. A small one-horsepower water pump was used to create current within the seine net to orient shad into the water flow. This current serves two purposes. Shad are concentrated in the flow to improve collection efficiency, and it separates the fish from the algae and detritus. Early juvenile survival increased in recent years due to the reduction of algae and detritus in the transport tanks. Early juveniles were transported to the Patapsco River in fish hauling tanks at 3.0-5.0 ppt. salinity and D.O. saturation to mitigate stress. Ponds at NRG Energy and AREL already have elevated salinity of 6.0-8.0 ppt. A one-horsepower trash pump was used to add water to the tanks to temper juvenile shad before stocking. Fish were tempered until temperature and salinity in the tank were within one degree Celsius (˚C) and 1.0 ppt salinity of the river value. Although this adds a considerable amount of time that the fish are aboard the transport tank, it is assumed this procedure reduces stress and increased early juvenile survival.

Biologists were concerned with the observed lack of feed at upstream stocking sites and decided to stock both larvae and early juveniles further downstream. Larvae were stocked at the Rt. 648 Bridge (Baltimore-Annapolis Boulevard) in Halethorpe, MD, and early juveniles were stocked at the public boat ramp near the South West Area Park (SWAP) in Halethorpe, MD. (Figure 1 and Figure 6).

Stocking Goals

The project developed stocking goals based on previous experience with juvenile collections (Table 1). Stocking multiple life stages gives fisheries managers the ability to assess larval survival and estimate juvenile mortality and abundance at each life stage.

Larval stocked fish can efficiently contribute large numbers of juveniles if survival is high. Fish stocked as early juveniles survive extremely well and are young enough to successfully imprint to the stocked tributary. Stocking early juveniles can also mitigate the impacts of poor larval survival since post-stocking survival of this life stage is high.

Table 1. *Maryland Department of Natural Resources 2014 American Shad stocking goals for the Patapsco River.*

Stocking phase	Stocking goal
Larvae	200,000
Early juvenile	75,000

Results and Discussion

American Shad Strip Spawn Production Summary

In 2014, large numbers of ripe female American Shad were collected from the Potomac River spawning area when temperatures ranged from 17°C to 22°C. A consistent increase in water temperature was observed throughout the 2014 American Shad spawning season until the last week of sampling, when temperatures decreased (Figure 5).

Since the 2001 project inception, a normal bell curve shaped distribution of egg production was observed in most years. Peak production was observed for only one week during the 2014 collection season (Figure 5).

The decrease in egg production in 2014 was attributed to unfavorable weather conditions throughout the American Shad spawning season (figure 3). Fish were collected only thirteen sampling nights, which is below the average number fished in previous years. Heavy rainfall events produced floating debris, turbid water, and extreme tides, which prevented gill net fishing on many nights. Observed CPUE increased in the 2014 season (Figure 3). This could reflect a strong spawning run, but the large number of zero effort sampling events during peak season creates some uncertainty in the 2014 relative abundance data.

MDNR collected 3,221 adult American Shad from the Potomac River. Five hundred and seventy nine ripe females produced 180 L of eggs. Overall fertilization was 52.2%. The estimated number of fertilized eggs produced was 3,346,406 (Table 2). Eggs collected from the Potomac River were used to produce larvae and early juveniles for the Patapsco River.

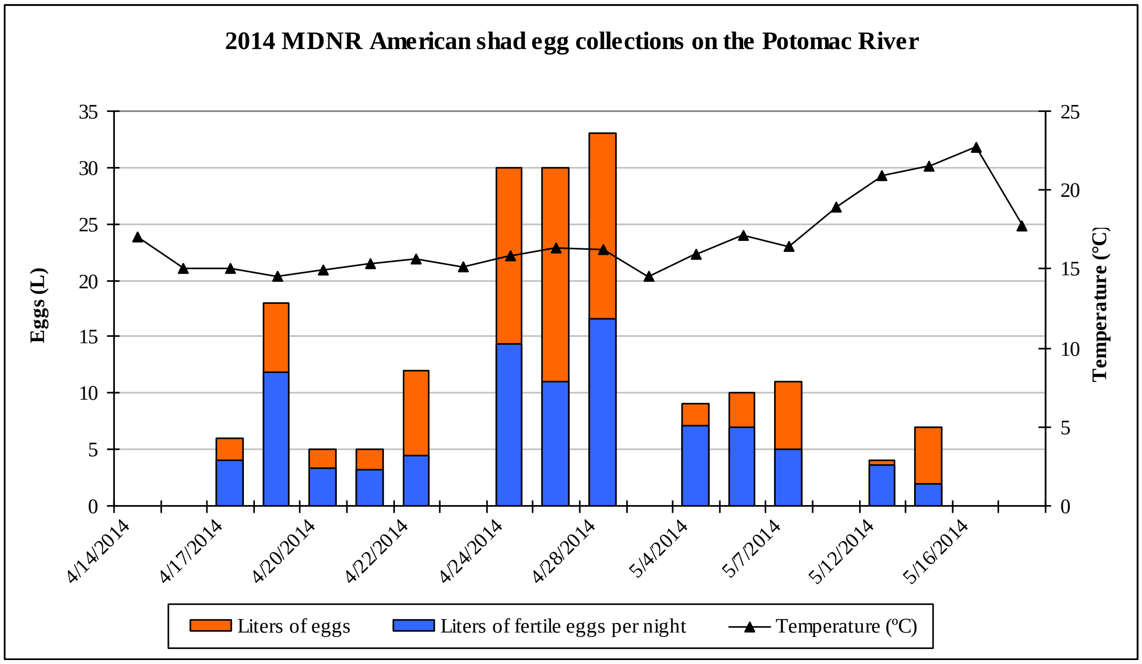

Figure 5. *2014 Maryland Department of Natural Resources volume of total American Shad eggs and viable eggs collected from the Potomac River*.

Table 2. *Maryland Department of Natural Resources 2014 American Shad brood fish and production data. Strip spawn collections were conducted on the Potomac River near Fort Belvoir, Virginia.*

Date	Ripe Females	Total shad	Liters of eggs	Liters of fertile eggs	Egg fertility	Total viable eggs
4/14/2014	7	101	0	0	0.00%	0
4/16/2014	8	111	0	0	0.00%	0
4/17/2014	15	143	6	4	68.00%	130,560
4/18/2014	41	163	18	12	65.63%	413,469
4/20/2014	27	147	5	3	68.00%	115,600
4/21/2014	9	163	5	3	65.00%	104,000
4/22/2014	26	215	12	4	37.00%	159,840
4/23/2014	4	96	0	0	0.00%	0
4/24/2014	68	287	30	14	48.00%	504,000
4/27/2014	143	487	30	11	36.86%	437,897
4/28/2014	101	379	33	17	50.40%	598,752
5/01/2014	0	4	0	0	0.00%	0
5/04/2014	23	80	9	7	78.26%	239,476
5/06/2014	26	222	10	7	69.76%	209,280
5/07/2014	28	155	11	5	45.57%	200,508
5/08/2014	5	99	0	0	0.00%	0
5/12/2014	13	109	4	4	90.16%	129,830
5/14/2014	30	217	7	2	28.35%	103,194
5/16/2014	5	41	0	0	0.00%	0
5/18/2014	0	2	0	0	0.00%	0
Total	**579**	**3,221**	**180**	**94**	**52.2%**	**3,346,406**

Stocking Summary

American Shad were stocked as larvae and early juveniles in the Patapsco River (Table 3, Figure 6). A summary of 2014 American Shad stocking production separated by event appears in Table 3.

American Shad larvae stocking goals were not met in the Patapsco River for 2014. The project was ultimately able to stock a large number of early juveniles, which are valuable to assess hatchery contribution (Table 3).

In 2014, a decline in the number of fertilized eggs brought into the hatchery negatively influenced larval stocking numbers. Unfavorable weather conditions during the egg collection season were responsible for this decline.

Table 3. *2014 Maryland Department of Natural Resources American Shad stocking events in the Patapsco River. Mark indicates the age in days when OTC was administered.*

Date	Life stage	Mark	Number
5/22/2014	larvae	Day 3	90,000
6/3/2014	early juvenile	Day 3, 6	70,000

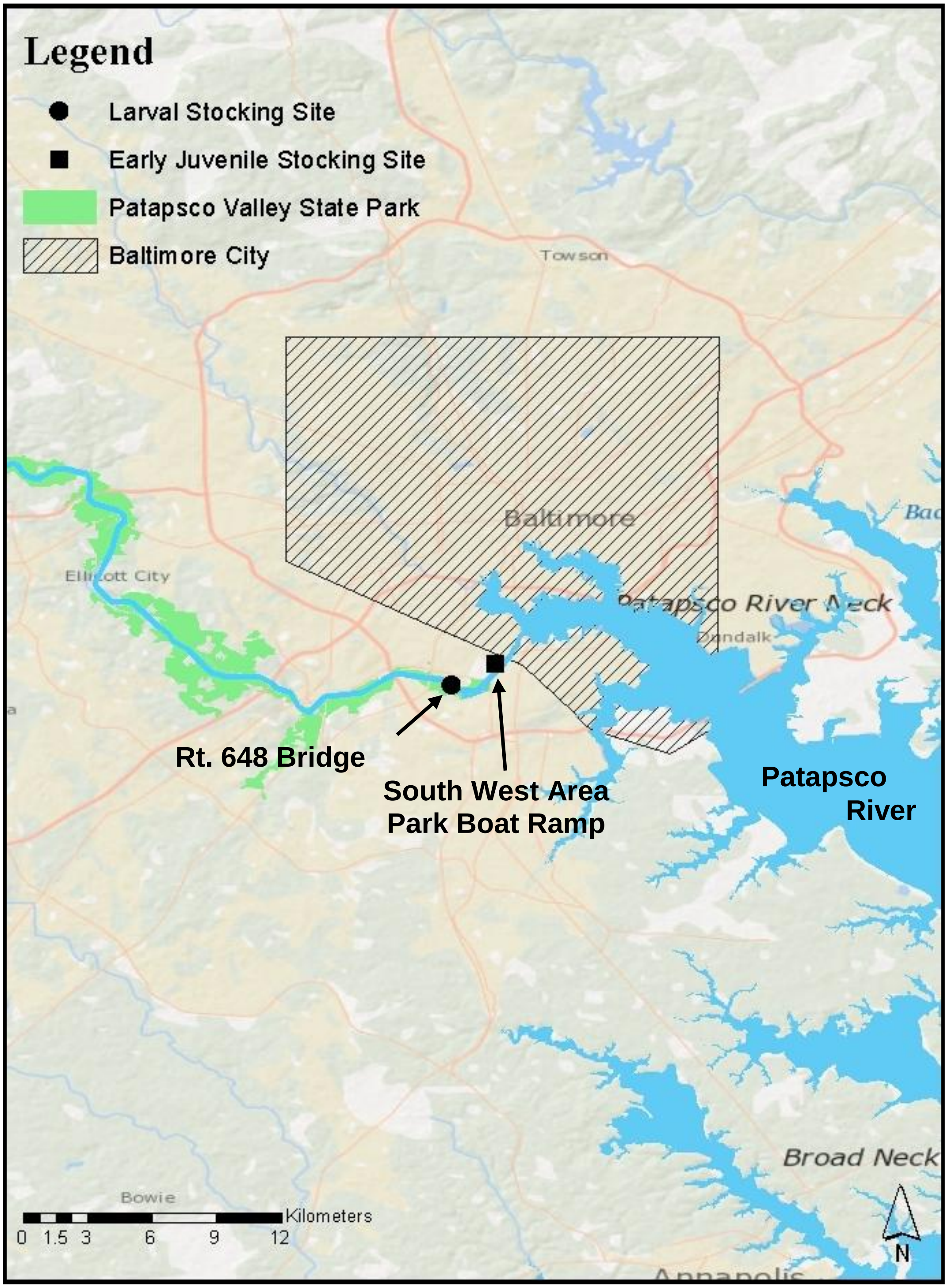

Figure 6. *Maryland Department of Natural Resources Patapsco River stocking sites in 2014. American Shad, Hickory Shad and river herring were stocked at the same locations.*

Hickory Shad

In 2014, MDNR staff produced, marked, and stocked Hickory Shad larvae and early juveniles into the Patapsco River (Figure 6). Early juvenile fish were first stocked as larvae into hatchery ponds and later transported to the river at approximately 30 days of age. Hickory Shad were produced through hormone-induced tank spawning from Susquehanna River origin brood fish.

Materials and Methods

Broodstock Collection

Hickory Shad broodstock were collected from the Susquehanna River (Figure 7 and Table 4). Since the mid-1990s, Hickory Shad abundances have increased in the upper Chesapeake Bay and its tributaries (ASMFC 1999).

Prior to 2005, Hickory Shad broodstock were collected by hook and line, either immediately downstream of Deer Creek or at Shure's Landing, near the base of Conowingo Dam (Figure 7). In 2005, MDNR staff transitioned to using an electrofishing boat to collect Hickory Shad brood. The sample area was along the western shore of the Susquehanna River, from just downstream of Deer Creek at Rock Run Mill down to the Lapidum boat ramp in the Susquehanna State Park (Figure 7). Electrofishing was used for its ability to efficiently collect larger numbers of Hickory Shad than could be collected by hook and line methods. Electrofishing for Hickory Shad broodstock requires less project staff and reduces handling stress. During brood collection, immobilized Hickory Shad were netted and placed in the electrofishing boat's hull-mounted live well (220 L). The live well water was recirculated, oxygenated, and treated with anesthetic (0.26 ml/L) 2-Phenoxyethanol,99% (Acros Organics, www.acros.com), to reduce stress and injury.

Hormone Induced Ovulation

Injections of Leutinizing Hormone-Releasing Hormone analog (LHRHa), a synthetic analog of gonadotropin-releasing hormone (GnRHa), stimulate pituitary release of endogenous gonadotropin. LHRHa induces gonadal maturation, ovulation and spawning (Mylonas et. al. 1995). In accordance with an Investigational New Animal

Drug Permit (INAD #11-375), MDNR purchased pre-made 75µg hormone pellets for ovulation induction. LHRHa pellets are sold under the product name Ovaplant® and produced by Western Chemical Inc. (Ferndale, WA, USA). When possible, Hickory Shad were implanted at the collection site on the Susquehanna River (Figure 7) to minimize stress from additional handling. Males and females received an intramuscular (IM) implant of Ovaplant® in the dorsal musculature. Implants were administered through a spring-loaded 11-gauge syringe or a multiple dose Ralogun® (Intervet/Schering-Plough Animal Health, The Netherlands).

Figure 7. *2014 Maryland Department of Natural Resources Hickory Shad broodstock collection site on the Susquehanna River.*

Table 4. *2014Maryland Department of Natural Resources Hickory Shad broodstock collected from the Susquehanna River by electrofishing boat.*

Date	Females	Males
04/14/14	23	41
04/16/14	9	54
04/22/14	77	113
04/24/14	117	140
04/28/14	22	6
05/01/14	28	26
05/05/14	12	14
05/06/14	53	12
05/08/14	34	16

Egg Culture

Broodfish were placed into circular flow 3,785 L tanks at 4.0-6.0 ppt salinity and transported to Manning Hatchery (Figure 1). Dissolved oxygen (D.O.) was continuously monitored and regulated to saturation (approximately 10.0 mg/L) with a Point Four oxygen monitoring system (Coquitlam, BC, V3K 6X9, Canada). Adults were transferred from the vehicle by rubber dip nets into 3.05 m diameter natural spawn tank systems. A sex ratio of approximately 3:2 male: female is preferable in natural spawn systems but there are times when males are not sufficiently available to meet this ratio. Salinity was maintained at 2.0 ppt. A 25% water change was performed each day to maintain adequate water quality. Fish spawned naturally and eggs were automatically transported to an egg collection box through an airlift system.

Eggs were volumetrically measured (eggs/2 ml) and fertilization was determined 24 hours post-spawn. Eggs were placed into modified McDonald hatching jars supplied by approximately 2.0 L/min water flow. Prophylactic treatments of formalin were administered in the morning and afternoon to control fungi at a rate of 600:1 treatment for approximately 17 min. Hickory Shad eggs began hatching at four days post-hatch. In order to stimulate a simultaneous hatch, jars were removed from the egg bank, placed outdoors in sunlight for ten minutes and stirred occasionally. The rapid temperature change, lower oxygen content, concentrated hormonal influence and agitation stimulated simultaneous hatching. Hatching jars were then placed on benches next to 1.5 m (1800 L) circular flow-through larval culture tanks that allowed water and larvae to flow from the hatching jars to the flow-through tanks. Water was supplied at approximately 2.0 L/min.

Hickory Shad feed on rotifers that are difficult to culture in the hatchery. Therefore, Hickory Shad were marked and stocked into hatchery ponds or target tributaries prior to first feeding (<six days age). Prior to stocking, larvae were enumerated using a volumetric direct proportion procedure in which a columnar sample of water was collected with a 25.0 mm diameter PVC tube at random locations in the larval tank. Larvae were enumerated in this sample and the total number of larvae in the tank was estimated by extrapolation to the total tank volume. In addition to this enumeration method, eggs were volumetrically measured and counted while performing the fertilization procedure.

Marking

All fish stocked in target tributaries were given an OTC mark to identify recaptured fish as hatchery origin. OTC marks applied to larvae or juveniles will persist in adults. Larval marks were produced by immersion in a buffered 300 ppm OTC bath for six hours. D.O. content was monitored and regulated (>5.0 ppm) by a carbon air stone connected to a liquid oxygen delivery system. All water used at Manning Hatchery for OTC marking was softened before use (Culligan ion exchange system). Reliable marking can only take place in water with hardness below 20 mg/L and water hardness at Manning Hatchery routinely exceeds 200 mg/L. Samples analyzed from each group of OTC marked fish indicated that all stocked fish were successfully marked. Marks were verified by viewing larval otoliths under UV microscopy (Zeiss Axioskop).

Larval Stocking

Fish intended for larval stocking were given an immersion mark at day one after hatch. Larval stocking was accomplished by placing OTC-marked larvae into boxes originally designed for shipping tropical fish. These containers consisted of an outer shell cardboard box, an inner insulating foam box, a black plastic trash bag to reduce stress of bright sunlight and a double thickness plastic fish transport bag. Larval culture tanks were drawn down to crowd the fish. Larvae were scooped out of the tanks and placed in the shipping bags/boxes, which were supplemented with salt (1.0 ppt) to mitigate transport and crowding stress. Each bag was filled with pure oxygen and sealed with electrician's tape. Boxes were driven to the stocking river and the bags were placed in the water to temperature acclimate (~45 minutes). The bags were then opened and river water was slowly introduced to further acclimate larvae to river water chemistry. Bags were then emptied into flowing water to minimize predation.

Early Juvenile Stocking

Fish intended for early juvenile stocking were given immersion marks at day one and three (1, 3) after hatch. After the final mark on day three was administered, larvae were stocked into hatchery ponds for approximately thirty days. Manning Hatchery and NRG Energy provide grow out ponds to culture fish for the restoration effort (Figure 1). The decision to take juveniles out of the pond is based on zooplankton composition, quality and density. Food availability is evaluated with plankton net. Early juveniles are removed from culture ponds when food availability declines.

Juvenile fish tend to stress easily and direct netting from hatchery ponds into transport tanks is not recommended. Juvenile fish were concentrated with a seine 61.0 meters long, 3.1 meters deep, with 6.4mm stretch mesh and bucketed with pond water into the transport tank. A small one-horsepower water pump is used to create current within the seine net to orient shad into the water flow. This current serves two purposes 1) current concentrates the shad for efficient collection and 2) separates fish from algae and detritus. Early juvenile survival increased in recent years due to the reduction of algae and detritus in the transport tanks. Early juveniles were transported in fish hauling tanks at 3.0-5.0 ppt. salinity and saturated D.O. to mitigate stress. Ponds at NRG Energy already have natural salinity of 6.0-8.0 ppt. so no additional salt is required. Juvenile stocking is usually accomplished by quick-dumping juveniles through a 15.0 cm hose directly from the transport vehicle into the river.

Biologists were concerned with the lack of food present at upstream sites and decided to stock both larvae and early juveniles further downstream. Larvae were stocked at the Rt. 648 Bridge (Baltimore-Annapolis Boulevard) in Halethorpe, MD, and early juveniles were stocked at the public boat ramp near the South West Area Park (SWAP) in Halethorpe, MD (Figure 1 and Figure 6).

For the past several years, MDNR biologists altered stocking procedures for early juveniles. A one-horsepower trash pump was used to add water to the tanks to temper juvenile shad before stocking. Fish are tempered until temperature and salinity in the tank are within one degree Celsius (˚C) and 1.0 ppt salinity of the river value. Although this procedure adds a considerable amount of time that fish are aboard the transport tank, it is assumed this procedure increases the survival of early juvenile stocked shad by reducing stress.

Stocking Goals

Larval stocked fish can efficiently contribute large numbers of juveniles if survival is high. In 2014, Hickory Shad larvae were proposed for stocking in the Patapsco River. The project stocking goal for the Patapsco River, which was based on previous experience with larval survival, was set at 500,000 larvae (Table 5).

Fish stocked as early juveniles survive extremely well and are young enough to successfully imprint to the stocked tributary. Stocking early juveniles can also mitigate the impacts of poor larval survival since post-stocking survival of this life stage is high. In 2014, Hickory Shad early juveniles were proposed for stocking in the Patapsco River. The project stocking goal for the Patapsco River, which was based on previous experience with juvenile survival, was set at 75,000 early juveniles (Table 5).

Table 5. *Maryland Department of Natural Resources 2014 Hickory Shad stocking goals for the Patapsco River.*

Stocking phase	Stocking goal
Larvae	500,000
Early juvenile	75,000

Results and Discussion

Hickory Shad Production Summary

Hickory Shad tank spawn production statistics are contained in Table 6. The fertilization rate for Hickory Shad was estimated at 29.2% in 2014. Since the program's inception, the average fertilization rate was 50.5%. Excluding the elevated fertilization rate of 2012, the past several years' Hickory Shad egg fertilization rates (Figure 8) and shad larval production (Figure 9) have been lower than expected. A potential cause of decreased Hickory Shad larval production was clumping of viable eggs in hatching jars. Egg clumping reduces larval escapement from hatching jars, which reduces hatching success. The cause of Hickory Shad egg clumping has not been adequately investigated in the past. Hickory Shad fertilization and clumping problems will be investigated in 2015. Various collection methods, anesthetic choices, brood and egg source water and gamete quality will all be investigated in conjunction with project production needs.

Egg de-adhesion techniques were investigated extensively in previous years. Egg de-adhesion techniques were adapted from methods described for Atlantic sturgeon by Mohler (2003). Eggs were treated with solutions containing fuller's earth and tannic acid. De-adhesion solutions containing 100-200 g of fuller's earth and 50-75 mg of tannic acid per gallon of water were used. Eggs were gently mixed in the de-adhesion solution for 20 minutes with a large feather. The egg de-adhesion solutions were effective for one to two days after treatment, but eggs would then clump together again. The agitation of eggs with a large feather in the hatching jars several times per day helped to minimize the clumping and caking of eggs prior to hatching.

Table 6. *Maryland Department of Natural Resources 2014 tank-spawn Hickory Shad egg production.*

Total eggs produced	29,068,775
Overall fertilization	29.2%
Fertilized eggs produced	8,498,525
Total larvae produced	520,000

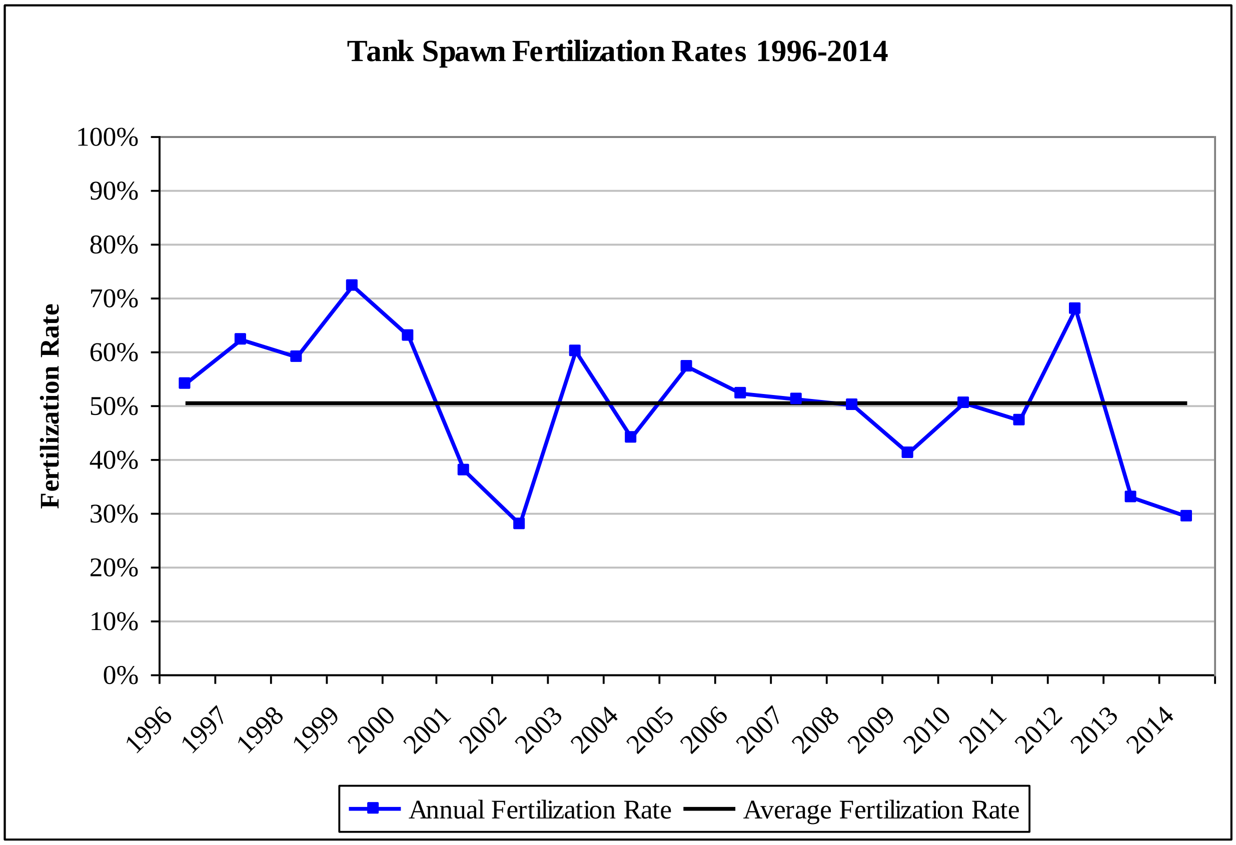

Figure 8. *Maryland Department of Natural Resources tank-spawn fertilization rates for Hickory Shad, 1996-2014. Average fertilization rates from 1996-2014 was 50.5%*

Stocking

In 2014, Hickory Shad were stocked as larvae at the Rt. 648 Bridge in Halethorpe, MD. Hickory Shad early juveniles were stocked at the boat ramp in the SWAP in Halethorpe, MD (Figure 1 and Figure 6). Some larvae were previously stocked in the Patapsco River (1998-2001) to investigate fish passage issues.

Hickory Shad larval stocking levels (465,000) did not meet project goals in 2014 (Table 5). The factors contributing to low larval production were low fertilization rates (Figure 8 Table 6), fewer available broodstock and clumping eggs in the hatching jars prior to hatch. Increased broodstock mortality was observed in hatchery broodstock spawning tanks this year. Factors that could contribute to pre-spawn broodstock mortality are transport stress, handling stress, anesthesia selection or prolonged anesthesia in the shock boat holding tank. Trials will be conducted in 2015 to investigate Hickory Shad broodstock and egg culture techniques. Early juvenile stocking levels (73,500) effectively met the 2014 stocking goal of 75,000. Stocking an adequate number of ponds and excellent survival from larvae to juvenile size produced large numbers of early juveniles. This success was also attributed to sufficient water quality and robust zooplankton blooms in Manning Hatchery and NRG Energy culture ponds (Figure 1).

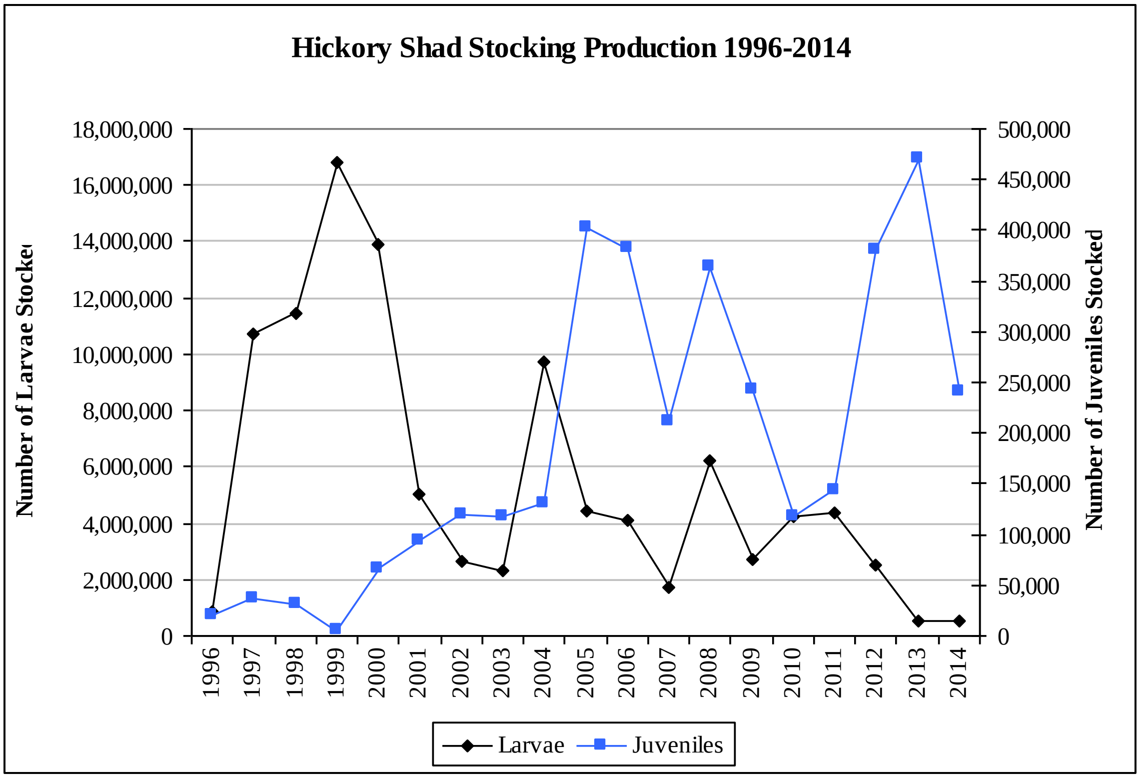

Figure 9. *Maryland Department of Natural Resources annual Hickory Shad stocking production in all tributaries, 1996-2014. The juvenile category includes fish stocked as early juveniles (June) and late juveniles (July/August). Fish were stocked in the Choptank River, Patuxent River, Nanticoke River, Patapsco River, and Chester River.*

Table 7. *Maryland Department of Natural Resources 2014 Hickory Shad stocking events in the Patapsco River.*

Date	Life stage	Mark	Number
4/23/2014	Larvae	Day 1	185,000
4/25/2014	Larvae	Day 1	150,000
5/4/2014	Larvae	Day 1	20,000
5/4/2014	Larvae	Day 1	110,000
6/2/2014	Early juveniles	Day 1,3	55,000
6/5/2014	Early juveniles	Day 1,3	5,000
6/9/2014	Early juveniles	Day 1,3	13,500

Table 8. *Historical stocking summary for larval and juvenile Hickory Shad in the Patapsco River since the inception of Hickory Shad restoration efforts (including fish passage work 1997-2004).*

Patapsco River Hickory Shad

Year	Larvae
1997	1,695,000
1998	250,000
1999	825,700
2000	500,000
2001	0
2002	0
2003	0
2004	542,000
2005	0
2006	0
2007	0
2008	0
2009	0
2010	0
2011	0
2012	0
2013	561,000
2014	538,500
Total	**4,912,200**

River Herring

In 2014, MDNR staff produced, marked, and stocked river herring larvae and early juveniles. For the purposes of this report, river herring will describe both Alewife Herring and Blueback Herring collectively. River herring larvae were marked and stocked into the Patapsco River (Figure 1). Early juvenile fish were first stocked as larvae into hatchery ponds and later transported to the river at approximately 30 days of age. River herring production needs were met by strip spawning brood fish from electrofishing efforts on the Choptank River and Patuxent River and seining at Morgan Run (Figure 10).

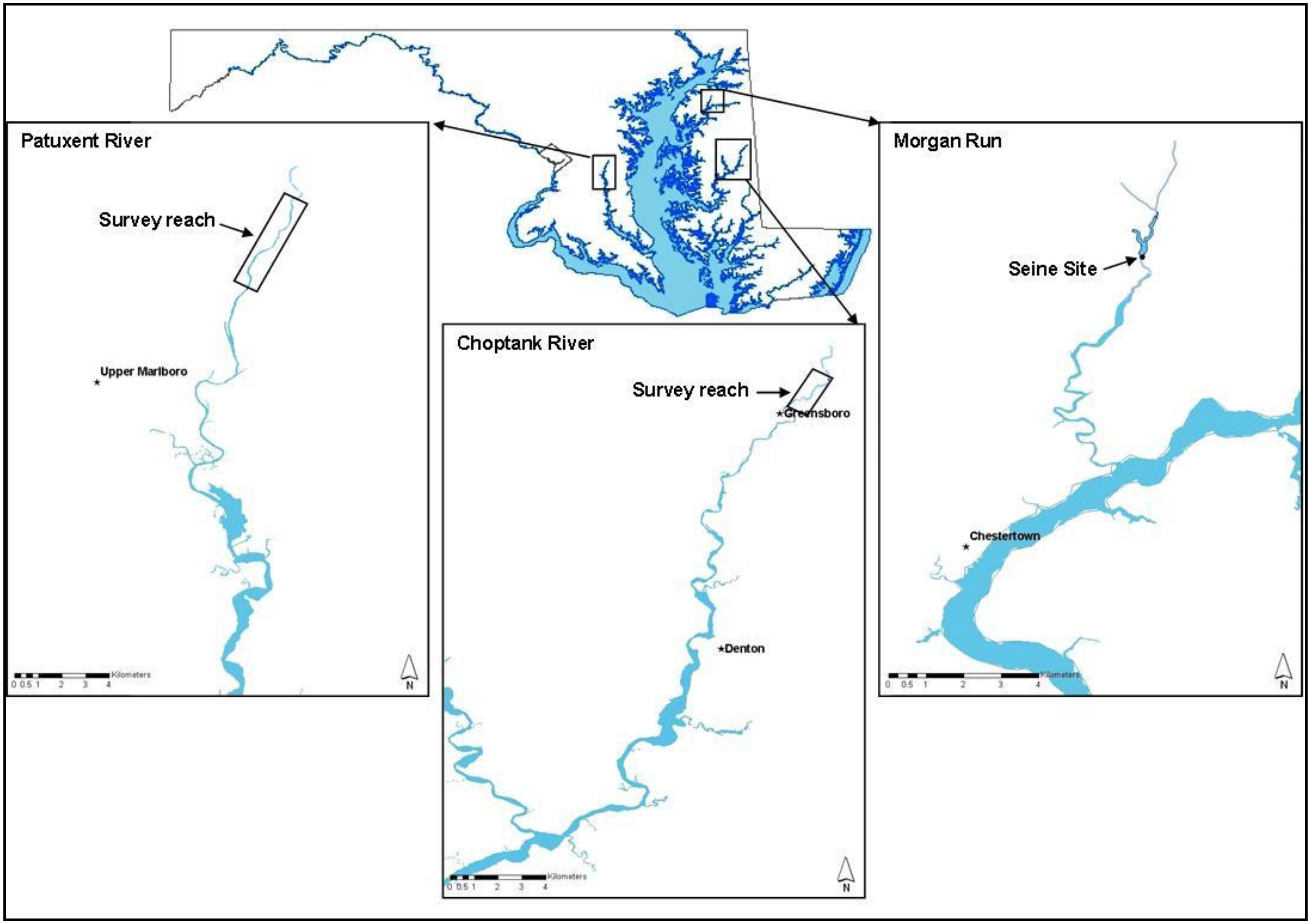

Figure 10. 2014 *Maryland Department of Natural Resources river herring broodstock collection area in the Patuxent River, Choptank River, and Morgan Run. Patuxent and Choptank rivers area sampled with electro-fishing boat. Morgan Run is sampled with a seine net.*

Broodstock Collection

The majority of the river herring broodstock were collected in the tail race of Urieville Lake (Morgan Run) in Kent County (Figure 10). Broodstock were also collected in conjunction with the F-57-R adult recapture survey from the Choptank and Patuxent rivers (Figure 10). To obtain gravid females, the sampling was conducted at dusk. Similar to American Shad, spawning in both species occurs diurnally and nocturnal, although most activity is nocturnal (Graham 1956). Weather and temperature conditions in late March and early April greatly influence the timing of river herring spawning. Alewife Herring spawn in late March to early April and Blueback Herring spawn in late April to early May. Sampling was conducted in historical spawning areas described by anecdotal data and concentrated in river sections where shad were encountered during previous sampling.

Seine net collection

Broodstock collection was conducted in the tail race of Urieville Lake (Morgan Run) with a seine 61.0 meters long, 3.1 meters deep, with 6.4mm stretch mesh, deployed in the tail race and pulled to shore by hand (Figure 10). Project biologists determined that Morgan Run indicated a substantial run of river herring and employed the large net to collect extremely large numbers (>500) of herring with one seine haul. A large pool below the lake enabled staff to easily employ this net. This technique was more efficient than electrofishing. Collection time was not dependent upon the tide, all fish were released alive after maturity examination, and sampling could be performed during daylight hours.

Electrofishing

Broodstock were also collected during previously described F-57-R electrofishing operations with a Smith-Root (Vancouver, WA) electrofishing boat model SR18-E at established sites (Figure 10). Target tributaries for the F-57-R project were sampled weekly from March 11 to June 10 during day time hours, coinciding with high tides. Brood collection was usually accomplished with three people. One person piloted the boat and two people netted fish from the bow. Alosines were encountered in areas that displayed similar physical characteristics. Sites are generally characterized as encompassing from the lowermost areas near the salt wedge to the uppermost areas just below the fall line. (Table 9, Figure 10). In the Patuxent River, this encompasses the area from the wastewater treatment plant located north of the intersection of Bayard Road and Sands Road (4500 block of Sands Road) to approximately 2.44 miles upstream just above the Patuxent River 4H Center. In the Choptank River, river herring were captured from just above the Route 313 Bridge in Greensboro, Maryland to approximately 1.28 miles upstream. In all of the targeted rivers it is likely that herring also utilize tidal freshwater areas downstream of our collection sites, but increasing river width and depth reduced capture efficiency with electrofishing gear.

Table 9. 2014 *Maryland Department of Natural Resources river herring broodstock collection starting and ending coordinates for target tributaries. *Morgan Run collection site is one collection point.*

River	***Starting latitude/longitude***	***Ending latitude/longitude***
Patuxent River	38° 53’ 08.24” N 76° 40’ 29.53” W	38° 51’ 05.09” N 76° 41’ 33.04” W
Choptank River	38° 59’ 11.91” N 75° 47’ 11.29” W	38° 58’ 36.79” N 75° 48’ 06.79” W
*****Morgan Run	39° 16' 42.68" N 76° 1' 27.47" W	

Electrofishing was used for its ability to efficiently collect larger numbers of fish. Electrofishing for river herring broodstock was conducted in conjunction with the F-57-R adult recapture survey. For this reason, it was very convenient to hold river herring for strip spawn. During brood collection, immobilized river herring were netted and placed in the electrofishing boat’s hull-mounted live well (220L). The live well water was recirculated, oxygenated, and treated with anesthetic (0.26 ml/L) 2-Phenoxyethanol,99% (Acros Organics, www.acros.com), to reduce stress and injury.

Egg Fertilization and Culture

Egg fertilization was conducted on the stream bank and aboard the electrofishing boat at the river. All collected herring were held in a flow through live well (electrofishing) or in a one meter diameter circular net pen (seine net method). Additional oxygen was added to the live well. Eggs were manually stripped into clean, dry bowls and milt was deposited over the eggs using the dry method described by Howey (1985). River water was then added to activate the sperm and mixed with a feather for three minutes. Once the eggs were fertilized, fuller’s earth was added to each bowl to eliminate the eggs adhesiveness and stirred for 10 minutes. Fertilized, de-adhesive eggs were then rinsed to be cleaned of any blood, ovarian tissue and fuller's earth and carefully poured into a floating egg box for at least one hour to water harden. This minimized egg damage during transport to the hatchery. Eggs were then placed into insulated larval transport boxes, injected with pure oxygen and sealed with black electrician's tape for transport to Manning State Fish Hatchery (Brandywine, Maryland) for culture (Figure 1).

Eggs were placed into modified McDonald hatching jars supplied by approximately 2.0 L/min water flow. Prophylactic treatments of formalin (600:1) were administered in the morning and afternoon for approximately 17 minutes to control fungi. Eggs were volumetrically measured at the hatchery and percent fertilization was determined 24 hours post-fertilization.

River herring eggs began hatching six days after fertilization. In order to stimulate a simultaneous hatch, jars were removed from the egg bank, placed outdoors in sunlight for ten minutes and stirred occasionally. The increased temperature, lower oxygen content, concentrated hormonal influence and agitation stimulated simultaneous hatching. Jars were then placed around 1.5 m circular, flow-through larval tanks. Water was supplied at approximately 2.0 L/min. Larvae flowed into circular culture tanks after hatch.

River herring feed on rotifers that are difficult to culture in the hatchery. Therefore, the herring were marked and stocked into hatchery ponds or target tributaries prior to first feeding (<six days age). Prior to stocking, larvae were enumerated using a volumetric direct proportion procedure in which a columnar sample of water was collected with a 25.0 mm diameter PVC tube at random locations in the larval tank. Larvae were enumerated in this sample and the total number of larvae in the tank was estimated by extrapolation to the total tank volume. In addition to this enumeration method, eggs were volumetrically measured and counted while performing the fertilization procedure.

Marking

All fish stocked in the target tributary were given an OTC mark to identify recaptured fish as hatchery origin. OTC marks applied to larvae or juveniles will persist in adults. Larval marks were produced by immersion in a buffered 300 ppm OTC bath for six hours. D.O. content was monitored and regulated (>5.0 ppm) by a carbon air stone connected to a liquid oxygen delivery system. All water used at Manning Hatchery for OTC marking was softened before use (Culligan ion exchange system). Reliable marking can only take place in water with hardness below 20 mg/L and water hardness at Manning Hatchery routinely exceeds 200 mg/L. Samples analyzed from each group of OTC marked fish indicated that all stocked fish were successfully marked. Marks were verified by viewing larval otoliths with a UV microscope (Zeiss Axioskop).

Larval Stocking

Fish intended for larval stocking were given an immersion mark at day one after hatch. Larval stocking was accomplished by placing OTC-marked larvae into boxes originally designed for shipping tropical fish. These containers consisted of an outer shell cardboard box, an inner insulating foam box, a black plastic trash bag to reduce stress of bright sunlight and a double thickness plastic fish transport bag. Larval culture tanks were drawn down to crowd the fish. Larvae were scooped out of the tanks and placed in the shipping bags/boxes, which were supplemented with salt (1.0 ppt) to mitigate transport and crowding stress. Each bag was filled with pure oxygen and sealed with electrician's tape. Boxes were driven to the stocking river and the bags were placed in the water to temperature acclimate (~45 minutes). The bags were then opened and river water was slowly introduced to further acclimate larvae to river water chemistry. Bags were then emptied into flowing water to minimize predation.

Early Juvenile Stocking

Herring intended for early juvenile stocking were given immersion marks at day one and three after hatch. After the final mark was administered, larvae were stocked into hatchery ponds for approximately thirty days. Manning Hatchery and NRG Energy provide grow out ponds to culture fish for the restoration effort (Figure 1). The decision to take juveniles out of the pond is based on zooplankton composition, quality and density. Food availability is evaluated with a plankton net. Early juveniles are removed from culture ponds when suitable food availability declines.

Juvenile fish tend to stress easily and direct netting from hatchery ponds into transport tanks is not recommended. A small one-horsepower water pump is used to create current within the seine net to orient shad into the water flow. Juvenile fish were concentrated with a seine and bucketed with pond water into the transport tank. This current serves two purposes. The current concentrates the shad for efficient collection and also separates fish from algae and detritus. Early juvenile survival increased in recent years due to the reduction of algae and detritus in the transport tanks. Early juveniles were transported in fish hauling tanks at 3.0-5.0 ppt. salinity and saturated D.O. to mitigate stress. Ponds at NRG Energy already have natural salinity of 6.0-8.0 ppt, so no additional salt was required. Juvenile stocking is usually accomplished by quick-dumping juveniles through a 15.0 cm hose directly from the transport vehicle into the river. In 2013, the scheduled Patapsco River stocking sites were not close enough to the road to use this method. Fish were acclimated in the truck and bucketed by hand to the river. In 2014, larvae and early juvenile stocking was accomplished at downstream sites that have suitable access for quick-dump stocking. Biologists were also concerned with the lack of food at upstream sites and decided to stock both larvae and early juveniles further downstream. Larvae were stocked at the Rt. 648 Bridge (Baltimore-Annapolis Boulevard) in Halethorpe, MD, and early juveniles were stocked at the public boat ramp near the South West Area Park (SWAP) in Halethorpe, MD.

For the past several years, MDNR biologists altered stocking procedures for early juveniles. A one-horsepower trash pump was used to add water to the tanks to temper juvenile shad before stocking. Fish are tempered until temperature and salinity in the tank are within one degree Celsius (°C) and 1.0 ppt salinity of the river value. Although this procedure adds a considerable amount of time that fish are aboard the transport tank, it is assumed this procedure increases the survival of early juvenile stocked shad by reducing stress.

Stocking Goals

Larval stocked fish can efficiently contribute large numbers of juveniles if survival is high. In 2014, river herring larvae were proposed for stocking in the Patapsco River. The project stocking goal for the Patapsco River, which is based on previous experience with larval survival, was set at 1,000,000 larvae (500,000 each for Alewife Herring and Blueback Herring, Table 10).

Fish stocked as early juveniles survive extremely well and are young enough to successfully imprint to the stocked tributary. Stocking early juveniles can also mitigate the impacts of poor larval survival since post-stocking survival of this life stage is high. In 2014, river herring early juveniles were not proposed for stocking in the Patapsco River. At the time of the proposal in 2010, it was unknown whether ponds at the culture facilities would have the proper food for herring production. The fish culturists attempted early juvenile production on an experimental basis and at least some of the culture ponds are capable of producing suitable plankton blooms for herring. While it is not a formal project goal, staff set an unofficial 2014 target of 150,000 early juvenile herring for the Patapsco River (75,000 each for Alewife Herring and Blueback Herring, Table 10).

Table 10. *Maryland Department of Natural Resources 2014 river herring stocking goals for the Patapsco River.*

Stocking phase	Stocking goal
Larvae	1,000,000
Early juvenile	150,000

Results and Discussion

River Herring Production Summary

Alewife Herring were collected from the Choptank River from March 9 to April 13, 2014. Eggs were also collected from Morgan Run and Unicorn Lake spillway on April 3, 2014. The fertilization rate was estimated at 87% for Alewife Herring in 2014 (Table 11). In 2014, Alewife herring were very abundant at Morgan Run and Unicorn Lake spillway. On April 3rd, 2014 staff collected more than one liter of eggs at 97% fertilization. This single collection event yielded 776,009 viable eggs. Future efforts will be concentrated at Morgan Run to minimize the time and effort required to collect broodstock for both herring species.

Blueback Herring were collected from the Choptank and Patuxent rivers from April 15 to May 14, 2014. The fertilization rate for Blueback Herring was estimated at

76% (Table 12). Blueback Herring broodstock collection proved troublesome. Males were very abundant and ripe with sperm during collection efforts. There were far fewer females available on the spawning grounds and only a few were running ripe at any one time. Herring runs of both species appear to begin and end within a very short period of time (24-36 hours, Smithsonian Environmental Research Center, Rob Aguilar pers. comm.).

River herring eggs are very adhesive post-fertilization. To successfully culture eggs, de-adhesion techniques were used at the river after fertilization to remove the adhesiveness of the eggs. Egg de-adhesion techniques were adapted from method's described for Atlantic sturgeon by Mohler (2003). River herring eggs were treated with100-200 g of fuller's earth. Eggs were gently mixed in the de-adhesion solution for 10 minutes with a large turkey feather. The agitation of eggs with a large feather in the hatching jars several times per day helped to minimize the clumping and caking of eggs prior to hatching.

Table 11. *Maryland Department of Natural Resources 2014 Alewife Herring broodstock collection data.*

Date	eggs (ml)	Fertilization (%)	Estimated Hatch	Origin
3/19/2014	490	n/a	80,000	Choptank
3/24/2014	406	90%	185,989	Choptank
4/3/2014	510	98%	336,365	Morgan Run
4/3/2014	665	96%	429,643	Unicorn Lake
4/13/2014	265	62%	93,487	Choptank

Table 12. *Maryland Department of Natural Resources 2014 Blueback Herring broodstock collection data.*

Date	eggs (ml)	Fertilization (%)	Estimated Hatch	Origin
4/15/2014	330	75%	156,668	Choptank
4/30/2014	400	62%	218,240	Susquehanna
5/2/2014	110	84%	60,984	Choptank
5/7/2014	100	80%	51,120	Patuxent
5/7/2014	200	85%	91,120	Choptank
5/9/2014	35	36%	6,754	Morgan Run
5/12/2014	405	85%	210,337	Choptank
5/14/2014	363	85%	203,952	Choptank
5/14/2014	332	90%	197,507	Choptank

Stocking

Larvae

In 2014, 700,000 Alewife Herring and 678,000 Blueback Herring larvae were stocked as larvae at the Rt. 648 Bridge (Baltimore-Annapolis Boulevard) in Halethorpe, MD. (Figure 6, Tables 13 and 14).

Early juvenile

95,000 Alewife Herring and 1,500 Blueback Herring early juveniles were stocked at the public boat ramp in the SWAP, Halethorpe, MD. (Figure 6, Tables 13 and 14).

Stocking goals for Alewife Herring and Blueback Herring larvae were met; however Blueback Herring early juvenile stocking levels did not meet project goals in 2014. Considering the brevity of the spawning period, staff biologists collected broodstock and eggs when they were available. In 2014, there were not enough suitable Blueback Herring broodstock encountered to produce larvae for juvenile grow out culture ponds. Collecting marginally ripe fish resulted in reduced fertilization rates and subsequently fewer viable eggs. Blueback Herring males were very abundant during all collection efforts, however very few gravid females were encountered. Electrofishing sampling was primarily conducted during daylight concurrent with the F-57-R adult recapture survey. In addition, an effort was made to collect gravid broodstock in the tail race of Urieville Lake (Morgan Run). A seine (61.0 meters long, 3.1 meters deep, 6.4mm stretch mesh) was deployed in the tail race and pulled to shore by hand (Figure 10). Extremely large numbers (>500) of herring were collected with one seine pull, but very few of the fish were gravid females. As stated previously, river herring early juveniles were not originally proposed for stocking in the Patapsco River. Culture efforts were successful for Alewife Herring early juveniles in 2014.

Table 13. *Maryland Department of Natural Resources 2014 river herring stocking events in the Patapsco River (EJ=early juvenile life stage).*

Date	Species	Life Stage	Mark	Number stocked
4/6/2014	Alewife	Larvae	Day 1	80,000
4/7/2014	Alewife	Larvae	Day 1	150,000
4/12/2014	Alewife	Larvae	Day 1	400,000
4/17/2014	Alewife	Larvae	Day 1	70,000

5/10/2014	Bluebacks	Larvae	Day 1	38,000
5/13/2014	Bluebacks	Larvae	Day 1	90,000
5/19/2014	Bluebacks	Larvae	Day 1	200,000
5/21/2014	Alewife	EJ	Day 1,3	65,000
5/21/2014	Bluebacks	Larvae	Day 1	350,000
5/22/2014	Alewife	EJ	Day 1, 3	30,000
6/5/2014	Bluebacks	EJ	Day 1, 3	1,500

Table 14. *Department of Natural Resources historic stocking summary for larval and juvenile river herring in the Patapsco River since the inception of restoration efforts 2012-2014*

Patapsco River River Herring

Year	Larvae	Early Juveniles
2013	830,000	164,000
2014	1,378,000	96,500
Total	**2,208,000**	**260,500**

Literature Cited

Atlantic States Marine Fisheries Commission. 2009. Atlantic Coast Diadromous Fish Habitat: A Review of Utilization, Threats, Recommendations for Conservation, and Research Needs, Habitat Management Series #9. Washington, D.C.

Graham, J. J. 1956. Observations on the alewife in freshwater. Univ. Toronto Biol. Ser. No. 62. 43pp.

Hildebrand, S.F. and W.C. Schroeder. 1928. Fishes of Chesapeake Bay. Bulletin of the U.S. Bureau of Fisheries. 43:99

Howey, R.G. 1985. Intensive culture of juvenile American Shad. The Progressive Fish-Culturist 47 (4): 203-212.

Klauda, R.J., S.A. Fischer, L.W. Hall and J.A Sullivan. 1991. American Shad and Hickory Shad in Habitat Requirements for Chesapeake Bay Living Resources, editors Steven L. Funderburk ... [et al.]; prepared for Living Resources Subcommittee, Chesapeake Bay Program; prepared by Habitat Objectives Workgroup, Living Resources Subcommittee [and] Chesapeake Research Consortium. Second edition, 1991 rev. ed., Annapolis, Maryland.

Mansueti, R.J. and H. Kolb. 1953. A historical review of the shad fisheries of North America. Chesapeake Biological Laboratory, Publication No. 97. Solomons, Md. : State of Maryland, Board of Natural Resources, Department of Research and Education.

Mohler, J. W. 2003. Culture manual for the Atlantic sturgeon, Acipenser oxyrinchus oxyrinchus. U.S. fish and Wildlife Service, Hadley, Massachusetts. 70 pp.

Mylonas, C., Y. Zohar, B. Richardson and S. Minkkinen. 1995. Induced spawning of wild American Shad Alosa sapidissima using sustained administration of gonadotropin-releasing hormone analog (GnRHa). Journal of the World Aquaculture Society 26(3):240-251.

O'Dell, J., J. Gabor and J. Mowrer. 1975. Survey of anadromous fish spawning areas for Chester River drainage in Queen Anne's County. Project AFC-9-2. Maryland Department of Natural Resources. Annapolis, Maryland.

O'Dell, J., J. Gabor and J. Mowrer. 1978. Survey of anadromous fish spawning areas for Potomac River drainage, Upper Chesapeake Bay drainage. Project AFC-9-1. Maryland Department of Natural Resources. Annapolis, Maryland.

Richardson, B., R. Morin, C. Stence and M. Baldwin. 2007. Restoration of American Shad and Hickory Shad in Maryland’s Chesapeake Bay. 2006 progress report for U.S. Fish & Wildlife Service Sport Fish Restoration Act grant No. F-57-7. Maryland Department of Natural Resources, Annapolis, Maryland.

Appendix 1

PATAPSCO SHAD AND HERRING RESTORATION

2014 Monitoring Progress Report

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Introduction

The Masonville Dredged Material Containment Facility (DMCF) was designed to accommodate Baltimore Harbor dredged material, which is statutorily required to be placed in a confined disposal facility. As a component of the DMCF project, the Maryland Port Administration (MPA) was required to develop a compensatory mitigation package to offset impacts associated with filling approximately 130 acres (53 hectares) of open water in the Patapsco River; a major tributary to the Chesapeake Bay. The mitigation projects focused , in part, on onsite and in-kind restoration of the adjacent Masonville Cove, including shoreline stabilization and erosion control, reef creation and substrate improvement, and creation and enhancement of tidal and non-tidal wetlands. Mitigation also incorporated offsite and out-of–kind mitigation projects. Under this mitigation category, Patapsco River shad and herring restoration was selected, and is the subject of this monitoring report.

The MPA has funded the Maryland Department of Natural Resources (DNR) to lead the Patapsco River shad and herring restoration effort. DNR contracted the U.S. Fish & Wildlife Service, Maryland Fishery Resources Office (MFRO) to perform monitoring activities of stocking efforts including field sampling and collections, laboratory sample preparation and interpretation, data analysis, and report writing. This report represents year two (Project year 3) of a five-year monitoring effort.

Need (From the project Scope of Work)

American Shad (*Alosa sapidissima*) was once the most important commercial and recreational fish species in the Chesapeake Bay. In response to severe population declines from 1900 to the 1970's, Maryland closed its fishery in 1980. Various factors that contributed to the decline include over-fishing, stream blockages, and poor water quality (Hildebrand and Schroeder 1928). Severely depressed or extirpated native adult stocks do not presently utilize most Chesapeake Bay tributaries, including the Patapsco River (Klauda et al., 1991). This tributary has historically supported spawning stocks. Improvements in water quality, sustained fishing moratorium, and planned removal of many stream blockages has reopened potential shad spawning habitat. Since shad show evidence of density dependent spawning behavior, self-sustaining shad populations are not likely to return to tributaries without hatchery inputs (Marcy 1976). Development of spawning, culture, marking, and stocking techniques could reintroduce and enhance spawning populations of American Shad to this target tributary. Funding obtained through Sport Fish Restoration Act F-57-R has supported a DNR shad restoration program since 1999 in other Maryland tributaries to the Chesapeake Bay. Substantial progress was previously documented in the Patuxent and Choptank rivers. Techniques and strategies developed in that program have been applied to Patapsco River restoration efforts.

Hickory Shad (*Alosa mediocris*) were historically abundant in many Chesapeake Bay tributaries. Recently, some upper Bay tributaries have experienced a mild resurgence in Hickory Shad runs. The availability of Hickory Shad brood stock provides the opportunity to culture and stock this species. Few studies have been conducted on Hickory Shad and little is known about their life history in Chesapeake Bay. Previous work conducted under F-57-R funding has yielded new Hickory Shad spawning strategy and life history information (Richardson et al., 2007). Many Bay tributaries had historical Hickory Shad runs equal to or greater than that of American Shad, and it could be useful to develop natural spawn, culture, and marking techniques for their restoration. These techniques have been refined during ongoing restoration projects, and have been applied to the Patapsco River.

River herring is the collective term for the Clupeidae Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*). These species have experienced recent declines coast-wide and throughout the Chesapeake Region. Dams have blocked much of the Patapsco River herring spawning habitat for decades. Recent and planned dam removal will reopen historical spawning habitat, and reintroduction and enhancement through hatchery inputs could have positive, local population impacts.

Maryland DNR restoration work thus far indicates that self-sustaining shad restoration will likely occur over a period of decades, rather than years. The Patuxent River has been stocked at a high level since 1994, and it has only been during the last several years that wild juvenile abundance has been increasing. Herring restoration would likely occur in a shorter time frame due to their younger age at maturity. The long time frame for American Shad restoration limits potential adult assessment activities considering the five-year monitoring funding commitment from the Masonville project. However, stocking larvae and juveniles for a period of three years at a high level should result in the presence of Patapsco River spawning adults in five to six years. Hickory Shad adults should return to the Patapsco River primarily at age three. Limited assessment of Hickory Shad adults will be conducted beginning in the third year of project monitoring, although some Hickory Shad adults could return at age two. Results for herring stocking should appear more quickly in adult sampling, and some indication of success could be apparent within the sampling timeframe. Larval and juvenile sampling for all target species will provide information on the current populations, and the impacts of stocking hatchery-cultured fish.

Objective

The overall objective of the Patapsco Shad and Herring Restoration Project is to introduce larval and juvenile American Shad, Hickory Shad, Alewife, and Blueback Herring populations to the river, and in so doing produce adult stock of hatchery-origin fish that will return to spawn. The objective of the monitoring component is to determine the extent to which the overall objective has been met by assessing the contribution of hatchery fish to the adult spawning population and, in comparison, monitoring recovery of naturally produced stocks.

Overall Project Expected Results and Benefits

Hatchery inputs are intended to provide adult spawning stock that could produce self-sustaining populations in the target tributary. These hatchery fish have tremendous value for stock assessment purposes at the larval, juvenile, and adult life stages since all stocked fish receive an oxytetracycline otolith mark. Natural spawn and strip spawn culture techniques allow for the production of large numbers of larval and juvenile shad and herring for stocking and assessment efforts.

Upper Bay shad populations currently support popular catch and release recreational fishing. Restoring shad and herring stocks to other tributaries that historically supported runs will increase fishing opportunities for anglers. Recreational fishing that targets Hickory Shad and American Shad is occurring in the Patuxent and Choptank rivers, primarily due to ongoing restoration efforts.

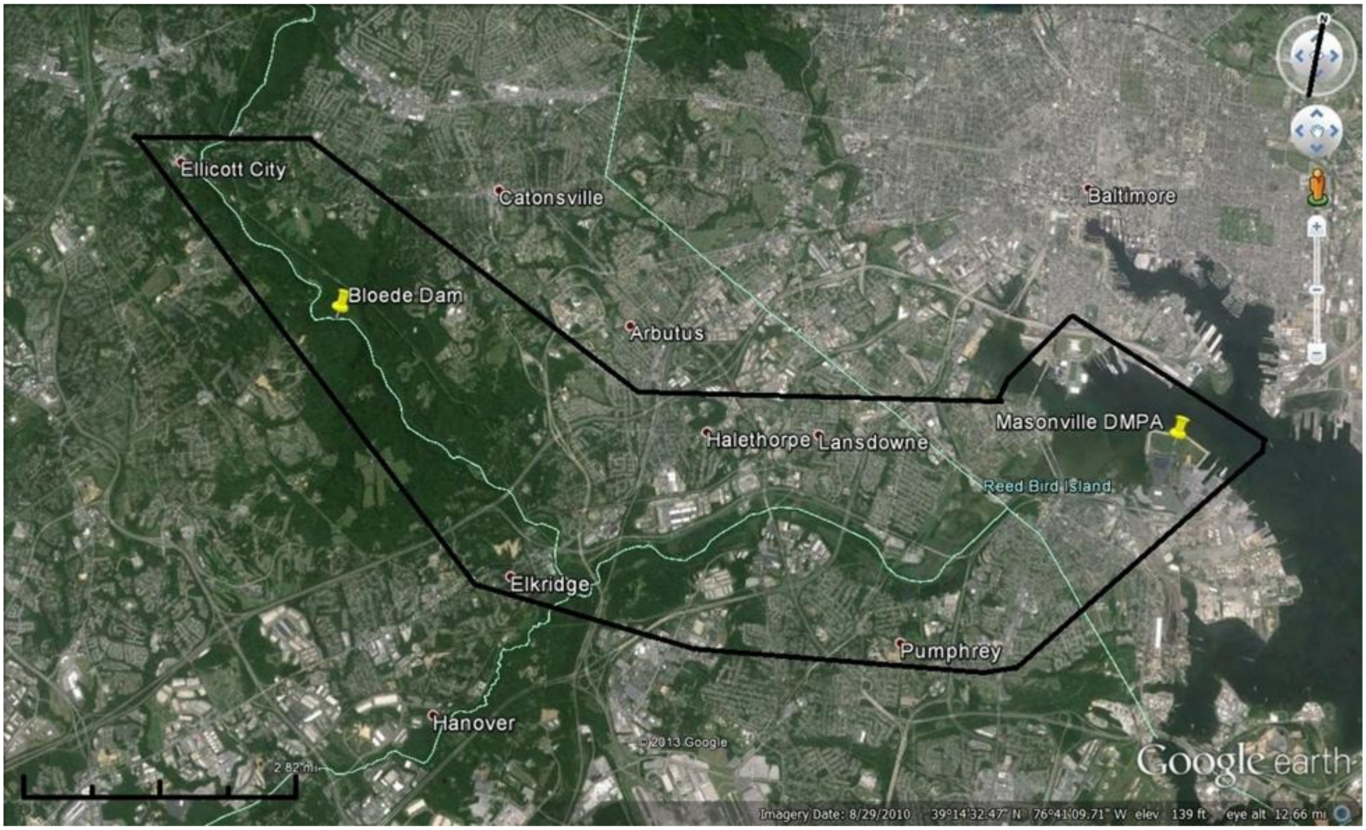
The Patapsco River watershed is heavily impacted by urban, commercial, and industrial development but has been the subject of numerous mitigation efforts due to its designation as a targeted watershed (i.e. sewage treatment upgrades and dam removals). If successful, this restoration effort should improve recreational fishing opportunities in the river. Figure 1 depicts the targeted watershed and river sections sampled.

Approach

The project consists of three sub-projects:

1. *Produce, mark, and stock cultured American Shad, Hickory Shad , and herring in the Patapsco River (Project years 1-4).*
2. *Monitor the abundance and mortality rates of larval and juvenile shad and herring using marked hatchery-produced fish (Project years 2-6).*
3. *Assess the contribution of hatchery fish to the adult Hickory Shad and herring spawning population (Project years 2-6).*

Figure 1. *2014 Patapsco River monitoring target area.*



Sub-project 1:
Produce, mark, and stock cultured American Shad, Hickory Shad, and herring in the Patapsco River.

Sub-Project 1 activities were conducted by the DNR, and are described in detail in the overall project report. The following briefly summarizes select sections of that report.

Under Sub-project 1, DNR developed stocking goals based on past experience with shad restoration. Alewife and Blueback herring early juveniles were not originally proposed for stocking as pond production at the hatcheries were unknown at the time.

Table 1**.** *2014 Maryland DNR shad and herring stocking goals for the Patapsco River. Early juveniles are stocked at approximately 30-d age.*

Species	Stocking Phase	Stocking Goal
American Shad	Larvae	200,000
American Shad	Early Juvenile	75,000
Hickory Shad	Larvae	500,000
Hickory Shad	Early Juvenile	75,000
Alewife	Larvae	500,000
Alewife	Early Juvenile	75,000
Blueback Herring	Larvae	500,000
Blueback Herring	Early Juvenile	75,000

Stocking

Manning State Fish Hatchery (Brandywine, Maryland) produced the larval and early juvenile fish stocked into the Patapsco River beginning in project year two. Project year one involved upgrades to the hatchery including pond construction and well installation. Stocking was accomplished outside the boundaries of Patapsco Valley State Park, which covers 32 linear miles (20 kilometers) of the Patapsco River, and encompasses 16,943 acres (6,492 hectares) in Howard and Baltimore Counties, Maryland. Stocking was performed in tidal portions of the Patapsco River, with larval stocking occurring where Route 648 crosses the river, and early juvenile stocking occurring at SW Area Park (Figure 2). Stocking began in early April 2014, and continued through early June 2014 (Table 2). All stocked fish received an oxytetracycline (OTC) Mark. Table 2 shows the day age of OTC larval immersion.

Figure 2. *Locations of Patapsco River stocking of larval (Route 648 Bridge) and early juveniles (SW Area Park) for 2014. Note different locations stocking sites of larval (red dot) and early juveniles (green dot) from 2013.*

Table 2. *Maryland DNR Patapsco River shad and herring stocking events in 2014. Species number stocked totaled: 795,000 Alewife, 160,000 American Shad, 679,500 Blueback Herring, and 538,500 Hickory Shad.*

Date	Species	Life Stage	Mark	# Stocked
4/06/2014	Alewife	Larvae	Day 1	80,000
4/07/2014	Alewife	Larvae	Day 1	150,000
4/12/2014	Alewife	Larvae	Day 1	400,000
4/17/2014	Alewife	Larvae	Day 1	70,000
5/21/2014	Alewife	Early Juvenile	Day 1,3	65,000
5/22/2014	Alewife	Early Juvenile	Day 1,3	30,000
5/22/2014	American Shad	Larvae	Day 3	90,000
6/03/2014	American Shad	Early Juvenile	Day 3,6	70,000
5/10/2014	Blueback Herring	Larvae	Day 1	38,000
5/13/2014	Blueback Herring	Larvae	Day 1	90,000
5/19/2014	Blueback Herring	Larvae	Day 1	200,000
5/21/2014	Blueback Herring	Larvae	Day 1	350,000
6/05/2014	Blueback Herring	Early Juvenile	Day 1,3	1,500
4/23/2014	Hickory Shad	Larvae	Day 1	185,000
4/25/2014	Hickory Shad	Larvae	Day 1	150,000
5/04/2014	Hickory Shad	Larvae	Day 1	20,000
5/04/2014	Hickory Shad	Larvae	Day 1	110,000
6/02/2014	Hickory Shad	Early Juvenile	Day 1,3	55,000
6/05/2014	Hickory Shad	Early Juvenile	Day 1,3	5,000
6/09/2014	Hickory Shad	Early Juvenile	Day 1,3	13,500

Sub-project 2:
Monitor the abundance and mortality of Patapsco River larval and juvenile shad and herring using marked hatchery-produced fish.

Materials and Methods

Sampling surveys were conducted to assess the larval and juvenile shad and herring populations in the Patapsco River. Two survey types attempted to capture early life stage shad and herring:

1. Larval ichthyoplankton drift or tow net survey.
2. Juvenile seine survey.

FIELD SAMPLING (LARVAL ICHTHYOPLANKTON NET)

Ichthyoplankton sampling began April 4, 2014 and continued through May 29, 2014. Maryland Biological Stream Survey (MBSS) participated with this portion of the study by conducting early life stage sampling using drift nets at two upper Patapsco River locations, upstream from the Route I 95 crossing of the river (Figure 3). On the lower section of the river, MFRO sampled two reaches downriver of the light rail crossing of the Patapsco using an ichthyoplankton tow net (Figure 4). Using both types of gear, sampling occurred once a week.

Drift nets were constructed of 360 micron mesh material, sewn into a cone 157 cm long attached to a square frame with a 300 x 460 mm opening. The stream drift net configuration and techniques were the same as those used by O'Dell et al. (1975). The frame was connected to a handle so that the net could be held stationary in the stream. Nets had a threaded collar on the end which allowed the connection of a Mason jar for sample collection. Nets were placed in the stream for five minutes with the opening facing upstream.

Due to low flows in the lower section of the river, tow nets were selected to augment the volume of water being sampled. Tow nets were constructed of the same mesh material and had the same dimensions, however the opening was a circular frame, with a diameter of 500 mm. Fauna collection via an attached Mason jar was the same. The net was fitted at the mouth with a flow gage (G.O. Environmental) in order to have the ability to calculate volume of water sampled. Additionally, a bullet float was attached above the mouth frame to keep the net off the river bottom. Nets were deployed off the stern of the boat and towed at a slow speed (< 6 knots) for five minutes at two different river reaches.

Upon retrieval, both types of nets were rinsed in the stream/river by repeatedly dipping the lower part of the net (cod end) and splashing water through the outside of the net to avoid sample contamination. The jar was then removed from the net and an identification label affixed describing site, date, time, and collectors. Another label with the same information was placed in the jar. Either during sampling, or at the end of the sampling day, all samples were preserved with 10% buffered formalin. Samples not preserved immediately were placed in a cooler. Prior to sealing each jar for transport, approximately 2 ml of Rose Bengal dye was added to each jar in order to stain any organism red to aid future sorting. Water temperature (^{o}C), conductivity

Figure 3. *2014 MBSS Patapsco River shad and herring larval ichthyoplankton sampling locations.*

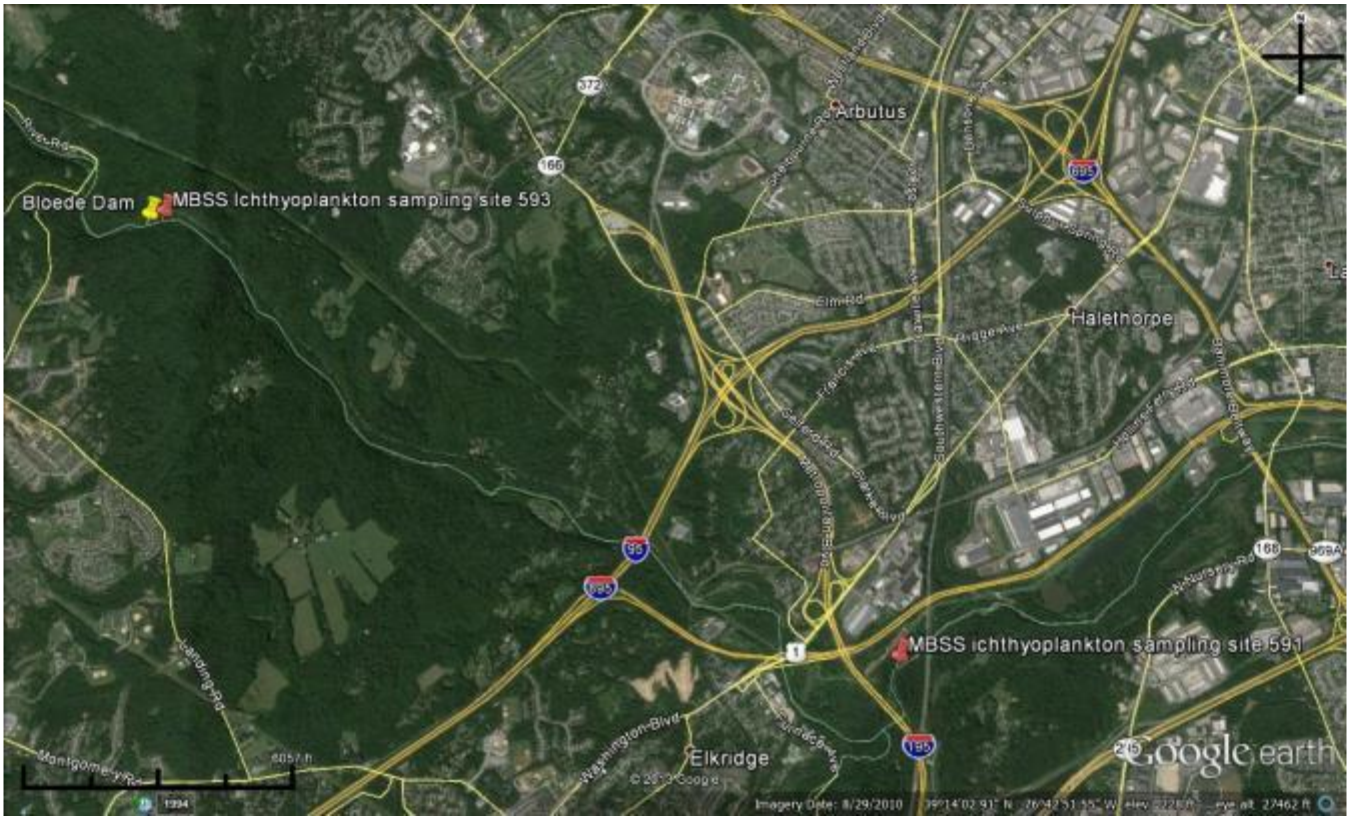
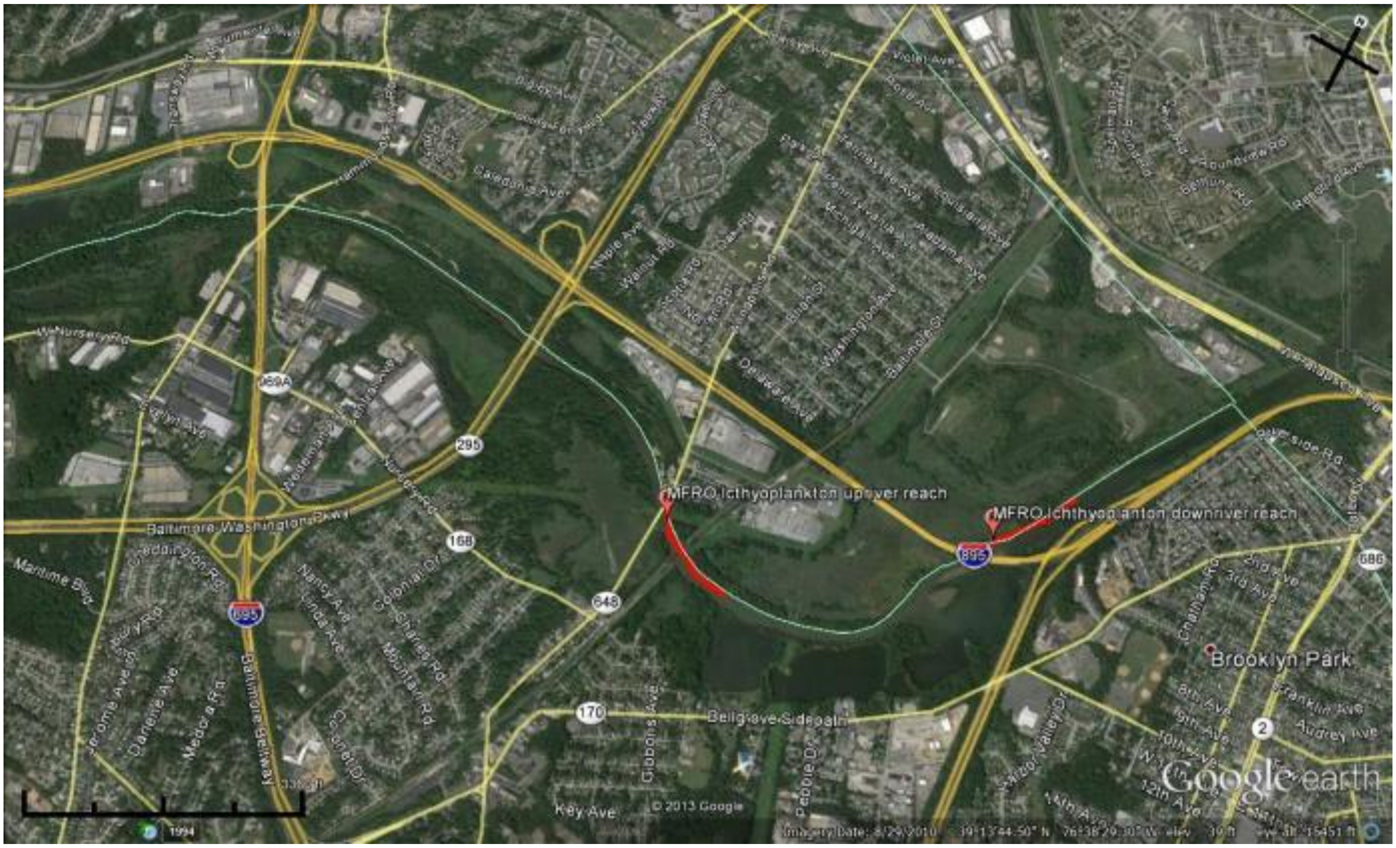


Figure 4. *2014 MFRO Patapsco River shad and herring ichthyoplankton sampling reaches.*



(µmho/cm), salinity (ppt), and dissolved oxygen (mg/L) were recorded at each site using a hand-held YSI model 85 meter (Yellow Springs, Ohio USA). All data were recorded on standard field data forms.

LAB ANALYSIS (LARVAL ICHTHYOPLANKTON NET)

Ichthyoplankton samples were sorted in the laboratory by MFRO personnel. All samples were rinsed with water to remove formalin and placed into a white sorting pan. Samples were sorted systematically (from one end of the pan to the other) under a 10x bench magnifier. All eggs and/or larvae were removed and retained in a small vial with a label (site and date), and fixed with 70% Isopropanol for later identification and/or counting under a microscope. Each sample was then systematically sorted a second time for quality assurance (QA). Any additional eggs/larvae found were removed and placed in a small labeled (site, date, and QA) vial and fixed with 70% Isopropanol for verification. All larvae found during sorting (both original and QA vials) were enumerated and identified as Alewife, Blueback Herring, Hickory Shad, or American Shad. The number of other species, and number of unknown or damaged species, was also recorded. Number of eggs was recorded, but no attempt was made at identifying to species.

Larval catch per unit effort (CPUE) was calculated for all target species as the geometric mean (GM) per tow haul. There were a large number of zeroes in the dataset, so a value of 1 was added to all values in order to calculate the GM. One was then subtracted from the resulting GM for back-transformation. Only back-transformed CPUE values are reported in the results section.

FIELD SAMPLING (JUVENILE SEINE)

The Patapsco River was sampled for juvenile Blueback Herring, Alewife, American Shad and Hickory Shad using fry and juvenile beach seines. Fourteen sites were initially chosen in 2013, but four of the non-tidal upriver sites were discontinued early in the study because no target species were encountered. The nine remaining sites were sampled in 2013, and an additional tenth site was added in 2014. The ten 2014 sampling sites are shown in Figure 5. Sampling was done weekly, beginning June 4, 2014 and ending on September 10, 2014. During the June 4 through June 11 period a fry seine was used, measuring 15.2 meters long, 2.4 meters deep, with 1.6 mm stretch mess. From June 19 through September 10 a beach seine was used, measuring 30.5 meters long, 1.24 meters deep, with 6.4 mm stretch mesh. Both types of seines were deployed by hand, starting at the shoreline and wading perpendicular to the shoreline out into the river, and then arcing back to that shoreline. Juvenile shad and herring were picked from the seine collection, identified to species, placed in plastic bags, labeled, and stored on ice. All other species were identified, enumerated and recorded, then returned to the river. Upon return to the lab, the retained samples were frozen. Only one juvenile Hickory Shad was encountered during the 2014 sampling. CPUE was calculated independently for each target species by calculating the geometric mean of catch data for each seine haul for each site. Zero catches were dealt with the same way as zero catches for ichthyoplankton sampling.

OTC mark presence/absence was determined by MFRO personnel using DNR's Matapeake Lab facility and equipment. Samples were first thawed and measured (fork length [FL] and total length [TL] in mm). Sagittal otoliths were removed by dissection, and mounted on 76.2 mm x 25.4 mm glass slides with Crystalbond 509 (Aremco Products, Ossining, NY). Mounted otoliths were lightly ground on 600 grit silicon carbide wet sandpaper and viewed under epi-fluorescent light at 400X magnification at 50-100 watts with a Zeiss Axioscope 20 microscope. Presence and location (day) of OTC mark epi-fluorescence was recorded. Epi-fluorescence is a technique in which transmitted light in the wavelength of 490-515 nm is allowed to strike the specimen. The specimen then absorbs this light energy and reflects light of a longer wavelength back through the microscope objective.

Figure 5. *2014 MFRO Patapsco River juvenile shad and river herring seining locations.*

Mortality and Abundance Estimates

In addition to providing future brood fish, juvenile stocking is valuable as a pre-migratory stock assessment tool through utilization of multiple mark-recapture techniques (Richardson et al., 2011). This also helps evaluate the efficacy of stocking different life stages and the eventual impact to the returning adult population. Calculation of stocked fish survival, in conjunction with juvenile and adult return data enables cost-benefit analysis of larval vs. juvenile stocking.

There are several assumptions made when using these types of estimates as described by Ricker (1975).

- The marked fish suffer the same natural mortality as the unmarked fish.
- The marked fish are as vulnerable to the fishing being carried on as are the unmarked one.
- The marked fish do not lose their mark.
- The marked fish become randomly mixed with the unmarked; or the distribution of fishing effort (in subsequent sampling) is proportional to the number of fish present in different parts of the body of water.
- All marks are recognized and reported on recovery.
- There is only a negligible amount of recruitment to the catchable population during the time recoveries are being made.

Estimates of juvenile shad and herring abundance, mortality, and survival was derived from the following:

Larval survival to juvenile stocking is calculated by Ricker (1975):

$$S_1 = (R_{12})\, M_2 / (M_1)\, R_{22}$$

$$\text{Variance } S_1 = S_1^2 \{(1/R_{12}) + (1/R_{22}) - (1/M_1) - (1/M_2)\}$$

where M_1 is the number of fish marked at the start of the first interval (larval stocking), M_2 is the number of fish marked at the start of the second interval (early juvenile stocking), R_{12} is recaptures of first interval marked fish in the second interval (after early juvenile stocking), R_{22} is recaptures of early juvenile interval marked fish in the second interval or (after early juvenile stocking), and S_1 is the survival rate of larvae during interval one (from the time of marking larvae in interval one to time of marking early juveniles in interval two).

Instantaneous mortality is derived from survival estimates and is used in conjunction with stocking data to calculate juvenile abundance

$$Z = -\ln S_1 / interval$$

where Z is instantaneous mortality rate and S_1 is survival rate

Abundance of juvenile herring and shad prior to migration is also calculated by Chapman's modification to the Peterson estimate (Ricker 1975):

$$N = \{(C + 1)(M + 1)\} / (R + 1)$$

Where *N* is the population estimate, *M* is the number of marked fish stocked, *C* is the number of fish examined for tags (total captures) and *R* is the number of marked fish that are recaptured.

From Ricker (1975): Calculation of 95% confidence limits based on sampling error using the number of recaptures in conjunction with Poisson distribution approximation.

Chapman's modification (1951):

$$N^{*} = \{(C + 1)(M + 1)\} / (R_1 + 1)$$

Where R_1 is from Pearson's formula to calculate upper and lower limits:

$$R_1 = R + 1.92 \pm 1.960\sqrt{R + 1.0}$$

The value (in larvae of stocking early juveniles can be evaluated by calculation (Richardson et al., 2007):

$$LV = \{ (J_c/J_s) / (L_c/L_s) \} (J_s)$$

where *LV* is the larval value of early juveniles stocked, J_c is the number of early juveniles collected, J_s is the number of early juveniles stocked, L_c is the number of larvae collected as juveniles, and L_s is the number of larvae stocked.

Sub-project 2 Measures of Success

1. Confirmed survival of stocked fish.
2. Calculate CPUE for each species and life stage sampled.
3. Identify the ratio of hatchery fish to wild fish for each species and life stage sampled. This will indicate current spawning success in the target tributary.
4. Calculate larval survival and juvenile abundance of herring and shad species.
5. Identify proportional origin of fish captured by species for each life stage. Origin will be designated as larval-stocked, juvenile-stocked, or wild. This will indicate the impact of stocking each life stage.
6. Early success will be indicated by a large proportion of hatchery-origin juveniles present on the spawning grounds.
7. Juvenile assessment in the third project year should indicate the increasing contribution of wild herring, and possibly Hickory Shad, produced from returning hatchery-origin adults.

8. Comparison of Patapsco River findings to the early years of previous successful restoration activities in the Patuxent River will indicate the impact of the stocking effort.
9. Cost-benefit analysis will indicate the most efficient stocking strategy for Patapsco River mitigation efforts.

Results and Discussion

ICHTHYOPLANKTON

Ichthyoplankton was sampled at four locations beginning April 4, 2014 and continuing through May 29, 2014. During this time frame 28 sampling events occurred encompassing the four locations. Table 3 shows upriver and downriver ichthyoplankton captures.

Table 3. *2014 Patapsco River downriver (MFRO) and upriver (MBSS) ichthyoplankton captures.*

Species	Downriver	Upriver
Alewife	11	0
Blueback Herring	28	15
Hickory Shad	0	0
American Shad	0	0
Non-target species	287	13
Unknown species	9	1
Unidentified eggs	303	2202

Considering targeted and non-targeted species, 11 larval Alewife Herring, 43 larval Blueback Herring and 300 larval non-alosine species were caught in 2014. There were no larval American Shad or Hickory Shad caught. The geometric means per ichthyoplankton tow were 0.19 for Alewife and 0.46 for Blueback Herring. The catches for Alewife and Blueback Herring increased from 2013 geometric means of 0.14 for both species. However, catches of larval American Shad and Hickory Shad decreased in 2014 (geometric means of 0.02 and 0.08 in 2013, respectively).

Interestingly, most of the ichthyoplankton biomass (with the exception of eggs) encountered occurred in the lower tidal fresh portion of the river: 92% of all larval fish, and 72% of all larval alosa were caught below Route 648. This is the same pattern that was observed in 2013 (95% of all larval fish and 84% of larval alosa). With Bloede Dam being a fish blockage to upstream areas in the Piedmont, this may suggest the lower tidal portion of the river provides better habitat for larval fish species at present. Much of the river between the dam and the Route 648 crossing has been impacted by sediment. Until Bloede Dam removal occurs, presumably in 2016, stocking the lower portion of the river in the vicinity of Route 648 should continue to be favored.

JUVENILE SEINE SURVEY

Weekly juvenile herring and shad surveys were conducted at ten sites on the Patapsco River (Fig. 5) using fry and beach seines between June 4, 2014 and September 10, 2014. By individual site 126 sampling events occurred.

Targeted species captured during seining included: 114 American Shad, 659 Blueback Herring, 21 Alewife, and 1 Hickory Shad (Table 4). In total, 42 species were collected, including 4,148 young of year (YOY) fish and 4,375 older fish. Other anadromous or semi-anadromous YOY captured were: 116 Striped Bass, 856 White Perch, and 154 Yellow Perch (Table 4). Geometric mean catch per seine haul for juvenile Alewife, American Shad, Blueback Herring, and Hickory Shad was 0.05, 0.42, 0.47 and 0.01 respectively. Only one juvenile Hickory Shad was encountered during the seine survey, and it was a wild fish. For all other target species, both wild and stocked fish were caught (Table 5). Table 6 lists the seine catch for marked and unmarked juveniles by sampling location. At least one juvenile target species was captured at each site. The highest catches of juvenile target species tended to occur in the intermediate sites (i.e. not at the most upstream or downstream sites), centered around Fisherman and Goose Point (Figure. 5).

Table 4. *2014 Patapsco River juvenile seining catch.*

Species	Young of Year	Age 1+
Alewife	21	
American Eel		5
American Shad	114	
Atlantic Menhaden	81	
Atlantic Needlefish	1	
Atlantic Silverside	109	832
Banded Killifish	23	616
Bay Anchovy	1	9
Black Crappie		1
Blacknose Dace	4	1
Blueback Herring	659	
Bluefish	9	1
Bluegill	24	48
Chain Pickerel	2	2
Channel Catfish	2	
Common Carp	1	4
Eastern Mosquitofish		5
Gizzard Shad	1063	193
Golden Shiner		1
Goldfish	2	
Hickory Shad	1	
Hogchoker	1	
Inland Silverside	18	592
Largemouth Bass	67	12
Mummichog	12	257
Naked Goby		1
Pumpkinseed	13	152
Quillback	262	53
Redbreast Sunfish	8	11
Rock Bass	1	
Satinfin Shiner		11
Sheepshead Minnow	1	
Smallmouth Bass	16	
Spotfin Shiner		72
Spottail Shiner	**57**	910
Striped Bass	116	1
Striped Killifish	15	307
Swallowtail Shiner		117
Tessellated Darter	159	65
White Perch	856	70
White Sucker	275	17
Yellow Perch	154	9
TOTAL	**4,148**	**4,375**

Table 5. *2014 Patapsco River juvenile seine catch for marked and unmarked shad and herring species. NS denotes no sample, where a targeted species was captured, but the otolith mark (OTC) was unreadable.*

Species	NS	Larval Mark Stock	Juvenile Mark Stock	Wild
Alewife	--	2	13	6
American Shad	3	40	65	3
Blueback Herring	4	12	0	220
Hickory Shad	--	--	--	1

Table 6. *2014 Patapsco River juvenile seine catch for marked and unmarked shad and herring species by sampling location. NS denotes no sample, where a targeted species was captured but the otolith mark (OTC) was unreadable. Not depicted is one juvenile Hickory Shad (no mark), which was captured at the Boat Ramp site.*

Sampling Location	Alewife				American Shad				Blueback Herring			
	Larval Mark	Juvenile Mark	No Mark	NS	Larval Mark	Juvenile Mark	No Mark	NS	Larval Mark	Juvenile Mark	No Mark	NS
Back Island	--	--	--	--	12	23	--	--	--	--	2	--
Boat Ramp	--	1	1	--	16	21	1	1	1	--	23	--
Borrow Pit	1	1	--	--	1	2	--	--	--	--	16	--
Fisherman Point	--	--	2	--	2	5	1	1	6	--	83	1
Goose Point	--	--	1	--	3	3	1	--	5	--	84	2
Harbor	--	--	--	--	--	--	--	--	--	--	1	--
I895 Bridge	--	--	1	--	5	8	--	1	--	--	1	--
Landfill	--	2	1	--	1	1	--	--	--	--	4	--
Light Rail	--	--	--	--	--	--	--	--	--	--	6	--
River Mouth	1	9	--	--	--	1	--	--	--	--	--	--

ABUNDANCE AND MORTALITY

Alewife
Survival of larval and juvenile stocked Alewives was confirmed by the capture of stocked fish from both life stages. Of the 21 juvenile Alewife otoliths successfully examined, 2 were larval stocked fish, 13 were juvenile stocked fish, and the remaining 6 were wild fish (Table 5). In 2013 no larval or juvenile stocked fish were captured, which suggests survival of hatchery fish increased in 2014. Larval survival to juvenile stocking (S_1) was 0.02 (σ^2=0.0003) and instantaneous mortality (Z) was 0.08. The total juvenile Alewife population in the Patapsco River is estimated to be 149,287 (95%CI: 89,879-243,412). The estimated abundance of wild juvenile Alewives is 42,654 (95% CI: 25,680-69,546). Population estimates from 2014 cannot be compared to 2013 because no hatchery released fish were captured in 2013. While survival of stocked fish appeared to increase in 2014, increasing survival of both larval and juvenile stocked Alewives should continue to be a priority in future stocking years. The calculated larval value of stocking 95,000 early juvenile Alewives was 4,550,000, or 47.9 larvae for every early juvenile stocked. If this value continues to be high in future project years, increasing the number of early juveniles stocked may be warranted, if resources allow.

American Shad
Survival of larval and juvenile stocked American Shad was confirmed through the seine surveys. Nearly all American Shad (96.9%) caught during seine surveys were hatchery stocked fish (Table 5). This is nearly the same percentage of hatchery fish captured in 2013, when 98.5% of American Shad juveniles captured were hatchery fish. Larval survival to juvenile stocking (S_1) was 0.48 (σ^2=0.009). Instantaneous mortality (Z) was 0.06. These results indicate stocking American Shad was successful, and that survival of larval and juvenile stocked life stages increased from 2013. There continues to be a relatively low contribution of wild fish to the population of juvenile American Shad. The larval value of stocking early juvenile American Shad was 146,250, or 2.09 larvae for every early juvenile stocked. If survival of larval stocked fish remains relatively similar to juvenile stocked fish, then it may be more cost beneficial to release a higher percentage of larval fish, as the cost to produce larvae is less than early juveniles.

The Chapman estimate for total juvenile abundance of American Shad in the Patapsco was 115,608 (95% CI: 91,005-146,742), an 18% increase in abundance from 2013 (N_{2013}=97,880). The wild juvenile abundance is estimated to be 3,211 (95% CI: 2,528-4,076). Based on these estimates, it appears the presence of juvenile American Shad in the Patapsco River is due largely to hatchery stocking efforts. However, the estimated wild juvenile abundance estimate more than doubled in 2014, from a 2013 estimate of only 1,461. It also appears that survival of larval stocked American Shad may have increased significantly in 2014, as no larval stocked fish were captured in 2013. The lack of wild American Shad within the juvenile samples is somewhat expected, given that only one mature adult American Shad was captured during adult sampling (see sub-project 3), and no larval American Shad were captured during ichthyoplankton surveys. There was also only one adult American Shad captured in 2013. Continued monitoring for the presence of wild American Shad should be a good indicator for restoration progress within the Patapsco River.

Blueback Herring

Larval stocked Blueback Herring were recaptured during seine surveys, thus confirming their survival (Table 5). However, survival of juvenile stocked Blueback Herring could not be confirmed, as none were captured. Of the 232 juvenile Blueback Herring otoliths examined, 220 were from wild fish (94.8%). The 12 recaptures of hatchery origin fish were all larval stocked fish. The survival rate (S_1) of larvae to juvenile stocking could not be calculated because no juvenile stocked fish were recaptured. One potential reason for no juvenile stocked fish being recaptured was due to low numbers of juvenile stocked fish. In 2014 only 1,500 juvenile Blueback Herring were stocked into the Patapsco River, as opposed to 57,000 stocked juveniles in 2013. No comparison was made between the larval value of stocking early juveniles of 2013 and 2014 because that value for 2014 could not be calculated because no stocked juveniles were recaptured.

The total population of juvenile Blueback Herring in the Patapsco River is estimated to be 12,178,749 (95% CI: 7,543,938-23,102,433). The total wild juvenile abundance for Blueback Herring is estimated to be 11,548,813 (95% CI: 7,153,735-21,907,479). These population estimates may be inaccurate (note wide confidence intervals around estimate), due to a low number of recaptured marked fish, and the large number of marked fish released. Survival may have been poor for marked fish, leading to low recapture rates. Increasing the likelihood of survival for both larval and juvenile-stocked fish should be of high importance. The high percentage of wild caught fish does suggest a strong remnant population within the Patapsco River.

Hickory Shad

Survival of larval or juvenile stocked Hickory Shad could not be confirmed because there were no stocked juvenile Hickory Shad caught during seine surveys. There was only one wild Hickory Shad juvenile caught during seine surveys. This was the first capture of a juvenile Hickory Shad during the project. Future seine survey work will continue to monitor for all target species' presence, including Hickory Shad. It may be difficult to monitor stocking success for Hickory Shad through juvenile seine surveys, because capture of juvenile Hickory Shad is difficult (Richardson et al. 2009). A better indicator of stocking success will likely be the return of hatchery stocked fish as adults, which could be detected during adult spawning surveys (see sub-project 3). For other rivers within Maryland this has proved to be a good measure of stocking success for Hickory Shad (Richardson et al. 2009).

HYDROLOGIC DATA

River flows in the Patapsco River were significantly higher in 2014 than in 2013. Average daily discharge measured at the USGS gauge at Hollofield MD was nearly twice as high in 2014 (423 cubic feet per second (cfs)) than in 2013 (221 cfs). Historic mean flows for the last 57 years at this site are 272 cfs. Several high flow events coincided with the spawning season for shad and river herring. There were three high flow events over 2000 cfs during April and May in 2014. There were no high flow events in 2013 over 1000 cfs during this timeframe. Increased flows during spawning season have been correlated to increased reproduction of anadromous species (Martino 2008). Higher numbers of wild fish captured and increased survival of stocked fish could be due to higher flows increasing the likelihood of spawning success and survival of stocked fish in 2014. Chesapeake Bay-wide seine survey indices for Alewife, American Shad, and Blueback Herring also support the notion that there was increased recruitment for shad and river herring compared to 2012 and 2013 (Durrell and Weedon 2014).

Sub-project 3:
Assess the contribution of hatchery fish to the adult American Shad and Hickory Shad and herring spawning population.

Adult assessment will document current populations of target species and monitor future adult returns of American Shad, Hickory Shad, and river herring. American Shad will not be fully recruited to the spawning population during the funding timeframe due to their later age at maturity. The funding timeframe does not permit robust monitoring or assessment of any adult Alosine populations. Adult sampling will take place in project years two through six.

Materials and Methods

Adult herring and shad surveys were conducted beginning March 20, 2014, and continued through May 29, 2014. Sampling occurred once a week, and was conducted by MBSS using a Smith-Root (Vancouver, WA) electrofishing boat in the upper, non-tidal portion of the study area (Figure 6), and by MFRO using a Smith-Root electrofishing boat in the lower, tidal portion of the study area (Figure 7). The upper section of the river was sampled at three river reaches, and the lower section was sampled at two river reaches, for approximately 1,000 to 1,500 seconds. Sampling occurred within the general vicinity of larval ichthyoplankton and juvenile collections. River reaches were sampled upstream to downstream, with constant voltage being applied for the entire run. Total shock time was recorded. All target species were externally examined for sex, measured for fork length (FL) and total length (TL), and enumerated for catch per unit effort (CPUE). Catch per unit effort was measured as total fish caught (per species) divided by shock seconds. Data were transformed to number of fish caught per hour. Analysis of variance (ANOVA) was done to examine any potential difference in FL between males and females.

Scale samples were taken for age analysis, and were aged using methods described by Cating (1953). Scales were independently examined for ages by two readers. If there was no consensus between the two readers, a third reader was used to examine scale age. If no consensus could be reached between all readers, or if scales were unreadable, they were excluded from analysis. In order to determine adult mortality of collected species, a catch curve analysis was done. Catch curve analysis was done by calculating the slope of a linear regression with natural log transformed total catch at age as the independent variable and age as the dependent variable. The slope of the line is equal to total instantaneous mortality for adults (Z). Catch curve analysis was done on fish aged 4 thru 6, because catch at age progressively declined after 4 years of age. Male and female catches were combined to calculate total catch for each species. Scales were also examined for spawning checks. The number of spawning checks was recorded for each scale examined. The first and second years of monitoring did not involve otolith extraction, as no hatchery origin adult fish would be expected. Subsequent project years (4-6) will involve otolith extraction, and assessment under epifluorescent light to identify hatchery-origin fish.

Sub-project 3 Measures of Success

1. Collect samples of adult shad and herring species.
2. Identify current presence of wild target species adults
3. Utilize length-frequency analysis to assess adult population structure.
4. Utilize age analysis to assess adult population structure.
5. Analyze proportional contribution of hatchery and wild origin adults.
6. Presence of hatchery adults indicates survival and fidelity. Absence does not necessarily indicate failure considering the truncated timeframe.

Figure 6. *2014 MBSS Patapsco River adult shad and herring electrofishing reaches.*

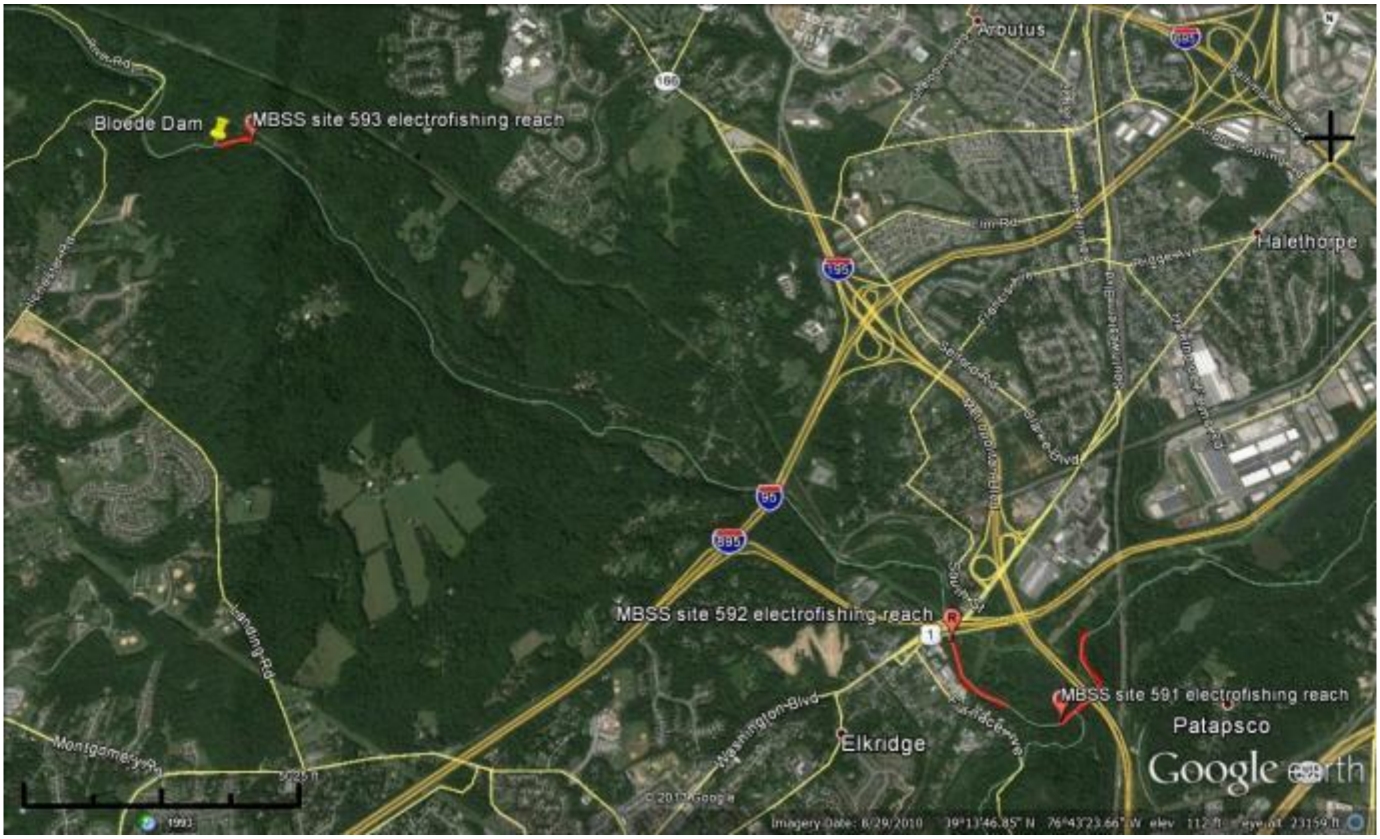
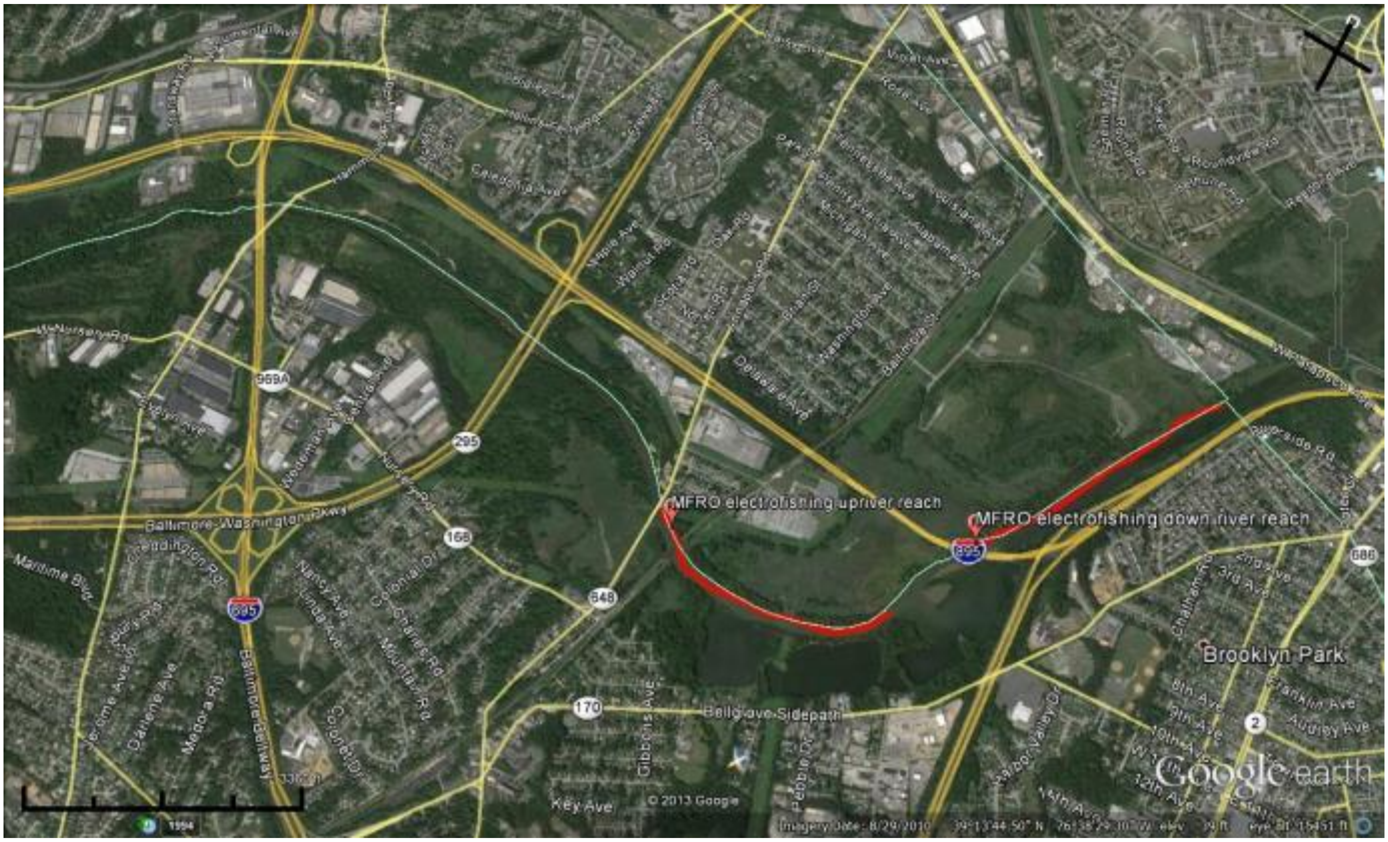


Figure 7. *2014 MFRO Patapsco River adult shad and herring electrofishing reaches.*



Results and Discussion

Adult shad and herring were sampled by electrofishing at five locations beginning in March 20, 2014 and continuing through May 29, 2014. During this time frame 43 sampling events occurred encompassing the five locations. A total of 109 Alewife Herring, 135 Blueback Herring, 21 Hickory Shad, and 1 American Shad were caught. Table 7 shows number of individuals caught by species and sampling location. An additional 35 adult Blueback Herring were captured via castnet by MBSS at site MBSS 593. Only one American Shad was caught, and that individual was encountered at an upriver MFRO sampling location. The downriver reach sampled by MFRO did not produce a high number of target fish. MBSS captures of targeted fish in the upper portion of the study area totaled 183 individuals. This is up slightly from the 2013 catch of 160 individual target fish. MFRO captures of targeted fish in the lower portion of the study area totaled 83 individuals (Table 7). This is more than twice the amount of target fish captured by MFRO in 2013 in the lower portion of the study area. This is largely due to the increase in catches of both Alewife and Blueback Herring.

The upper (MBSS) portion of the adult shad and herring sampling area may have allowed for better capture rates of targeted species. The shallow depth and high water clarity may have increased capture efficiency as compared to the lower (MFRO) portion of the study area which is deeper and turbid. Additionally, the blocking effect of Bloede Dam most likely concentrated fish in the upper reach. Regarding the low catch of American Shad, Maryland DNR experience has shown that this species can more easily avoid electrofishing capture than the closely related Hickory Shad. The result is that American Shad adults are probably not fully represented in spawning ground sampling. The larval and juvenile survival, mortality and abundance estimates presented in sub-project two of this report can serve as an important indicator of restoration progress.

Catch rates for most species were generally similar, with the exception of American Shad (Fig. 8). Catch-per-unit effort for all species ranged from 0.0-124.4 fish per electrofishing hour. The highest catch rates occurred for Blueback Herring collected in mid-May. Alewife and Hickory Shad were encountered during mid- to late April, with Blueback Herring not encountered until late April. This follows expected patterns due to the spawning behavior of each species, with Alewives and Hickory Shad spawning prior to Blueback Herring. Species were encountered relatively later in the year, compared to 2013. Generally, catches peaked about 1-2 weeks later in 2014 than 2013. This was likely due to a colder than normal winter and early spring.

Both males and females were encountered for all species except for American Shad (Table 8). The single American Shad captured was a female with a FL of 405 mm. It was 6 years old and a repeat spawner. Female to male ratio varied for all species (with the exception of American Shad). Males dominated the catches of Alewives, with nearly 3 males for every female. Hickory Shad male to female ratio was 1.85:1, and Blueback Herring male to female ratio was 1.73:1. These rates were all higher than in 2013, when ratios for all species were approximately 1.5:1. Adult ages ranged from 3 to 6 for all captured river herring and shad (Fig. 9; Table 9). For Alewife and Blueback Herring, the majority of fish were age 3. In 2013, the dominant age class for Alewife and Blueback Herring was age 4. The dominant age class for Hickory Shad was age 4, the same as in 2013. No age 3 fish of any species was a repeat spawner (Table 9). This is an expected result, as age 3 should be the age when most fish become sexually mature and make their first spawning run. As fish became older, there were more repeat spawners. However, in 2014 there was a significant reduction from 2013 in the overall percentage of repeat spawners for each species. In part, this is likely due to the dominant age class being age-3 fish for river herring spp., which should be spawning for the first time. The only increase in repeat spawners from 2013 was for female Blueback Herring, which increased from 0.0% in 2013 to 15.0% in 2014. In the future, continued monitoring of the number of repeat spawners of Blueback Herring will be important to measure successful restoration of this species. In 2015, it is possible that fish stocked in 2012 will be returning to the river to spawn for the first time. Analysis of otoliths from adults will be done in 2015 to determine contribution of stocked fish to the adult population.

Length range for all species collected is shown in Figure 10. Average length at age for each species, listed by sex is shown in Table 10. Females were generally larger than males for all species. There were significant differences between male and female lengths for Alewife and Blueback Herring, but not for Hickory Shad (Alewife ANOVA, $F_{1,81}=19.39, p<0.001$; Blueback Herring ANOVA, $F_{1,106}=37.47, p<0.001$; Hickory Shad ANOVA, $F_{1,18}=1.75, p=0.20$). All adult fish captured in 2014 were aged; therefore a length at age key was not developed for fish this year. In future years, assuming catches increase, a length at age key will be developed to help determine ages for fish that do not undergo scale analysis. However, for all species there was a high amount of overlap among lengths at age (Table 10), which suggests length may not be a good surrogate for age.

Total instantaneous mortality rates (Z) for adults were 1.98 for Alewife and 1.12 for Blueback Herring. Mortality could not be calculated for Hickory Shad because only two year classes were captured. The corresponding survivorship rates for Alewife and Blueback Herring are 0.14 and 0.33, respectively. Alewife mortality increased slightly from 2013 (Z=1.72). Mortality for Blueback Herring decreased approximately 40% from 2013 (Z=1.88). Mortality estimates for both species are generally in agreement with previous river herring and shad studies conducted along the Atlantic Coast (Grist 2005; Armstrong 2008). Mortality rates will continue to be monitored through age analysis in project years 4 thru 6.

Table 7. *2014 Patapsco River adult shad and herring electrofishing catches by sampling location.*

Sampling Location	Alewife	American Shad	Blueback Herring	Hickory Shad
MBSS 591	62	--	40	15
MBSS 592	14	--	29	1
MBSS 593	3	--	18	1
MFRO Downriver	2	--	3	1
MFRO Upriver	28	1	45	3

Table 8. *2014 Patapsco River adult shad and herring electrofishing catches by species and sex.*

Species	Male	Female	Total
Alewife	62	21	83
American Shad	--	1	1
Blueback Herring	69	40	109
Hickory Shad	13	7	20

Table 9. *Number of adult Alewife (A), Blueback Herring (B), and Hickory Shad (C) captured in the Patapsco River in 2014, listed by sex and age. The number of repeat spawners is listed by species, sex, and age. Not depicted is one American Shad, which was a 6 year old female.*

A) Alewife

Age	Male		Female		Total	
	N	Repeat	N	Repeat	N	Repeat
3	42	0	11	0	53	0
4	19	0	10	2	29	2
5	1	1	0	0	1	1
Totals	*62*	*1*	*21*	*2*	*83*	*3*
% Repeats	*1.6*		*9.5*		*3.6*	

B) Blueback Herring

Age	Male		Female		Total	
	N	Repeat	N	Repeat	N	Repeat
3	45	0	21	0	66	0
4	20	3	15	3	35	6
5	3	0	4	3	7	3
Totals	*68*	*3*	*40*	*6*	*108*	*9*
% Repeats	*4.4*		*15.0*		*8.3*	

C) Hickory Shad

Age	Male		Female		Total	
	N	Repeat	N	Repeat	N	Repeat
3	5	0	3	0	8	0
4	8	2	4	0	12	2
5	0	N/A	0	N/A	0	N/A
Totals	*13*	*2*	*7*	*0*	*20*	*2*
% Repeats	*15.4*		*0.0*		*10.0*	

Figure 8. *Electrofishing catch-per-unit effort (CPUE) for all adult river herring and shad species captured on the Patapsco River in 2014. Note: only one American Shad was caught for all trips and occurred on May 15, 2014.*

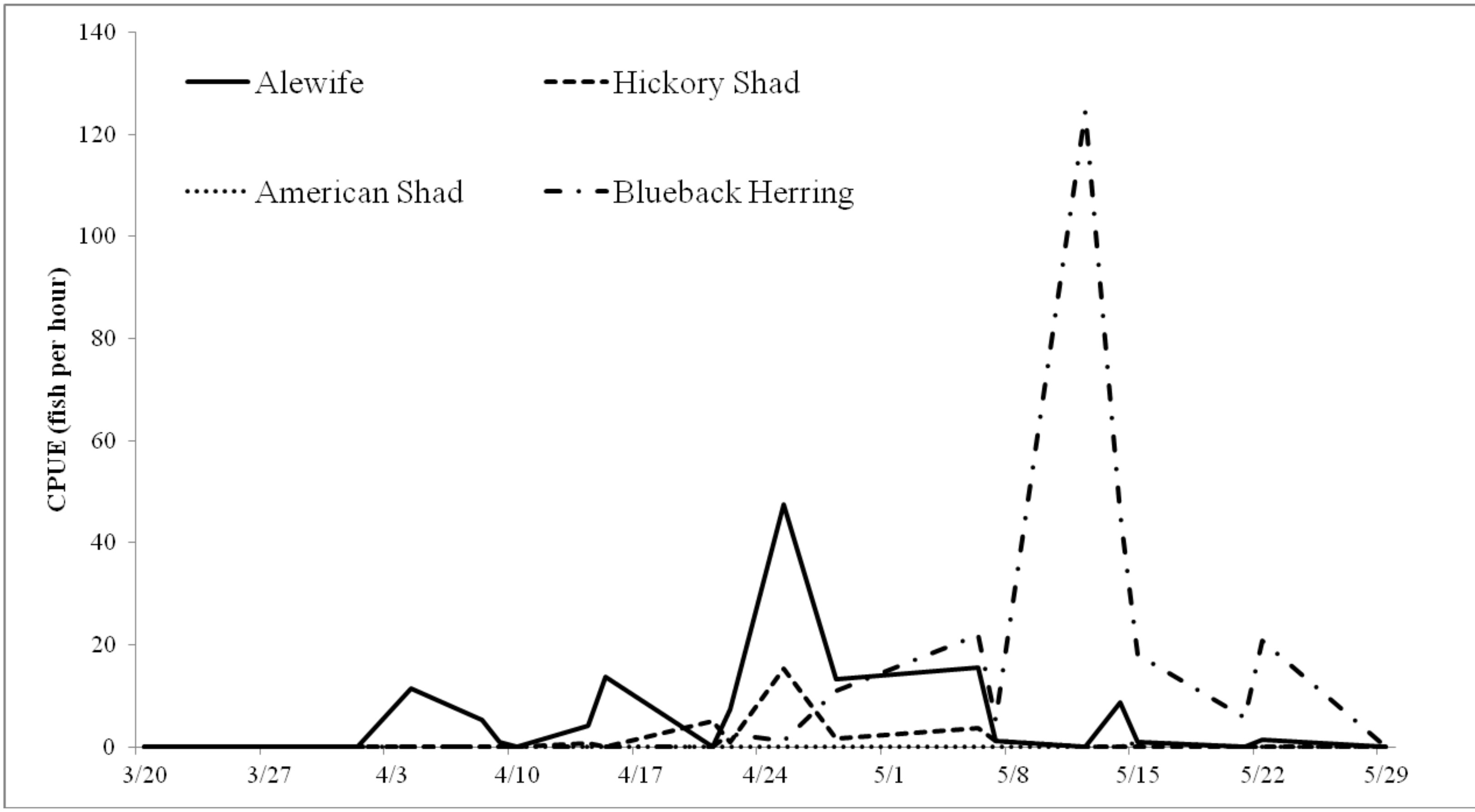


Figure 9. *Catch at age for Alewife, Blueback Herring, and Hickory Shad captured in the Patapsco River in 2014. Not depicted is one American Shad, which was 6 years old.*

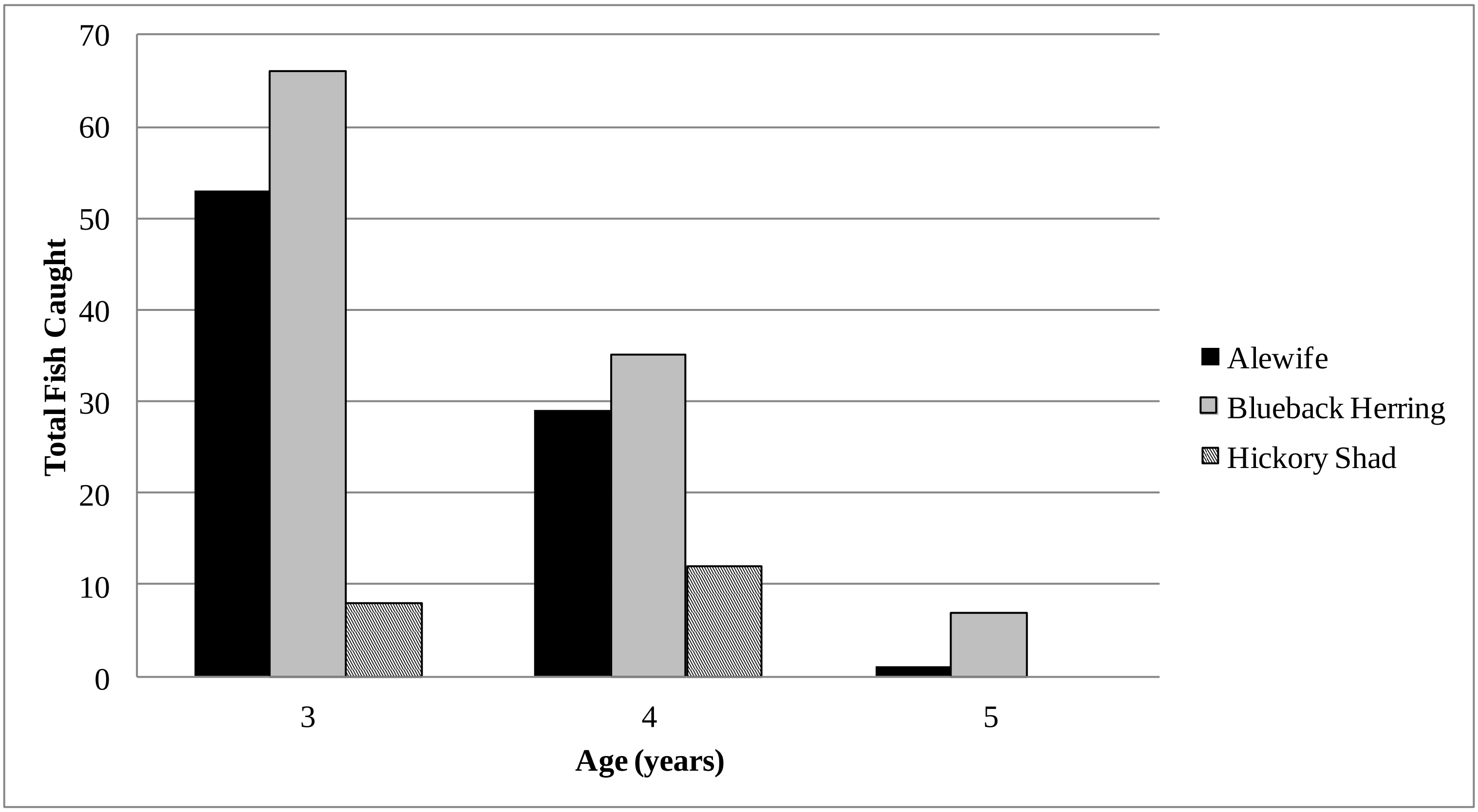


Figure 10. *Length- frequency for adult Alewife (A), Blueback Herring (B), and Hickory Shad (C) captured during electrofishing trips on the Patapsco River in 2014. Note the differently scaled axes for each species.*

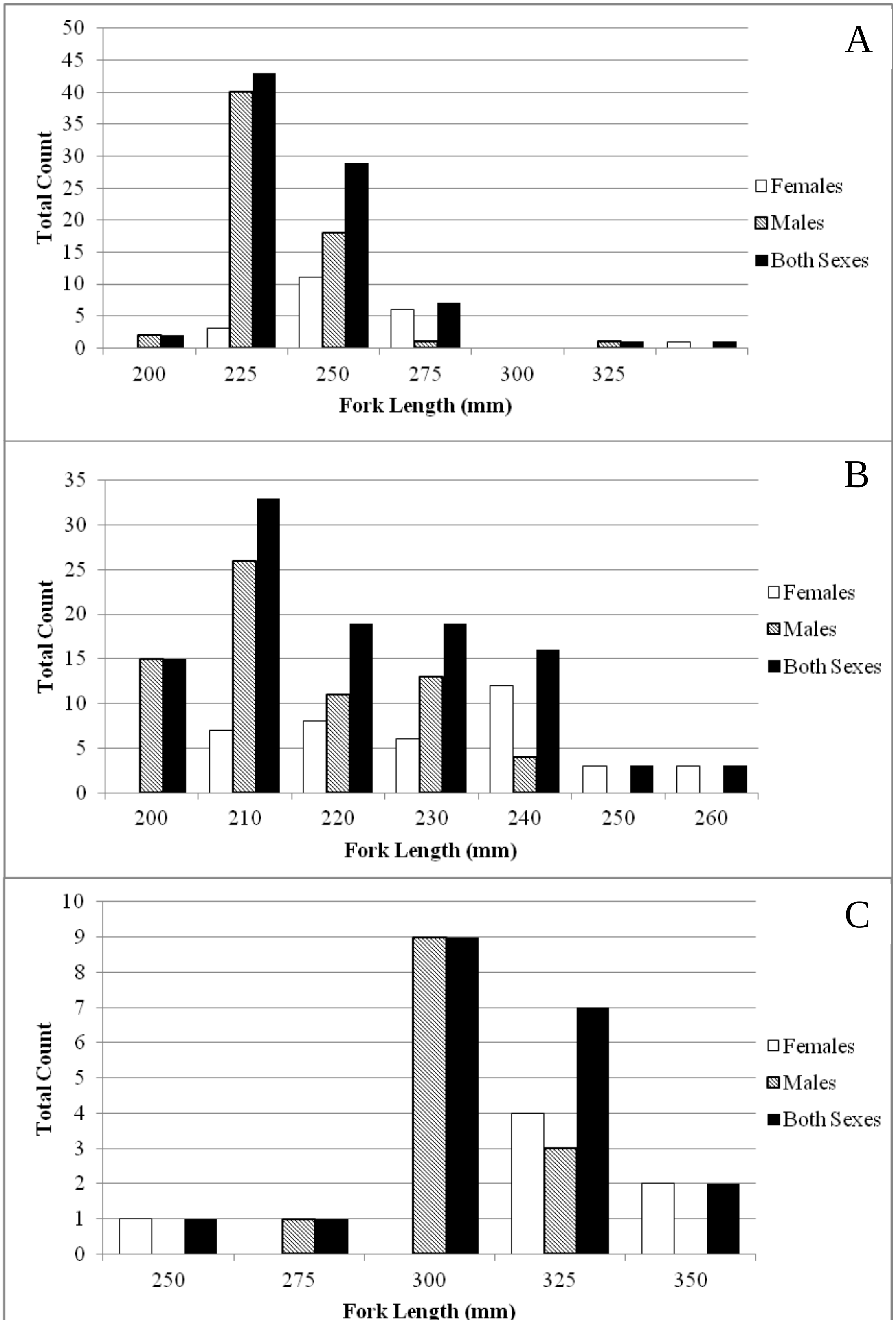


Table 10. *Sex-specific length at age (±SD) for Alewife, Blueback Herring, and Hickory Shad adults collected from the Patapsco River in 2014. Instantaneous natural mortality (Z) is listed for each species in its entirety. Not depicted is one American Shad, which was 6 years old.*

	Alewife		Blueback Herring		Hickory Shad	
Age	Male	Female	Male	Female	Male	Female
3	221 *(20)*	245 *(32)*	204 *(7)*	215 *(12)*	318 *(19)*	307 *(39)*
4	221 *(13)*	244 *(15)*	221 *(11)*	235 *(7)*	313 *(8)*	349 *(17)*
5	226 *(0)*		222 *(4)*	243 *(8)*	N/A	N/A
Z	1.99		1.12		N/A	

Overall 2014 Project Monitoring Conclusions

- While survival of stocked Alewives appeared to increase in 2014, increasing survival of both larval and juvenile stocked Alewives should continue to be a priority for future stocking years. The calculated larval value of stocking 95,000 early juvenile Alewives was 4,550,000, or 47.9 larvae for every early juvenile stocked. If this value continues to be high in future project years, increasing the number of early juveniles stocked may be warranted, if resources allow.

- There continues to be a relatively low contribution of wild fish to the population of juvenile American Shad (nearly all, 96%, caught during seine surveys were hatchery stocked fish). The larval value of stocking early juvenile American Shad was 146,250, or 2.09 larvae for every early juvenile stocked. If survival of larval stocked fish remains relatively similar to juvenile stocked fish, then it may be more cost beneficial to release a higher percentage of larval fish, as the cost to produce larvae is less than early juveniles.

- Population estimates given in the report for Blueback Herring may be inaccurate due to the low number of recaptured marked fish, and the large number of marked fish released. Larval stocked Blueback Herring were recaptured, thus confirming their survival. However no juvenile stocked Blueback Herring were recaptured. Survival may have been poor for marked fish. The high percentage of wild caught fish does suggest a strong remnant population within the Patapsco River.

- Survival of larval or juvenile stocked Hickory Shad could not be confirmed because there were no stocked juvenile Hickory Shad caught during seine surveys. There was only one wild Hickory Shad juvenile caught during seine surveys. This was the first capture of a juvenile Hickory Shad during the project. A better indicator of stocking success will likely be the return of hatchery stocked fish as adults, which could be detected during adult spawning surveys.

- Upper coastal plain, the area between the Route 648 crossing of the Patapsco River and Bloede Dam, appears to be impacted by course grained sediment. Alosid larval and juvenile habitat is lacking.

- Lower tidal fresh portion of the river appears to be functional habitat for larval and juvenile shad and herring species as well as for other anadromous and semi-anadromous species.

- Stocking in the lower portion of the river, in the vicinity of Route 648 and SW Area Park, should continue until such time when Bloede Dam is removed.

- Bloede Dam removal scheduled in 2016 will open the piedmont region to alosid species. That habitat could be of better quality than what is available downstream of the dam in the non-tidal portion of the river.

- Extending stocking and assessment could determine the effects of dam removal on restoring shad and river herring in the upper watershed. Current funding only pays for three years of stocking and five years of assessment. For shad in particular, Maryland DNR restoration work thus far indicates that self –sustaining restoration will likely occur over a period of decades, rather than years. With dam removal not slated until 2016, present funding will not address the benefits of Bloede Dam removal to shad and herring in the upper watershed.

Literature Cited

Armstrong, M.P., J.J. Sheppard, and P.D. Brady. 2008. Biological Characterization and Enhancement of American Shad (*Alosa sapidissima*) and Alewife (*Alosa pseudoharengus*) Populations in Massachusetts Coastal Streams. NOAA Fisheries. 78p.

Cating, J.P. 1953. Determining age of Atlantic shad from their scales. Fishery Bulletin 85, Fishery Bulletin of the Fish and Wildlife Service, Volume 54.

Chapman, D.G. 1951. Some properties of the hypergeometric distribution with applications to Zoological samples censuses. University of California Publ. Stat. 1(7): 131-160.

Durell, E.Q., and Weedon, C. 2014. Striped Bass Seine Survey Juvenile Index Web Page. http://dnr2.maryland.gov/fisheries/Pages/juvenile-index/index.aspx. Maryland Department of Natural Resources, Fisheries Service.

Grist, J. 2005. Stock Status of River Herring 1972-2004. N.C. Div. Mar. Fish. 63p.

Hildebrand, S.F. and W.C. Schroeder. 1928. Fisheries of Chesapeake Bay. Bulletin of the U.S. Bureau of Fisheries. 43:99.

Klauda, R.J., S.A. Fischer, L.W. Hall and J.A. Sullivan. 1991. American Shad and Hickory Shad in Habitat Requirements For Chesapeake Bay Living Resources, editors Steven L. Funderburk…[et al.]; prepared for Living Resources Subcommittee, Chesapeake Bay Program; prepared by Habitat Objectives Workgroup, Living Resources Subcommittee [and] Chesapeake Research Consortium. Second edition, 1991 rev. ed., Annapolis, Maryland.

Marcy, B.C., Jr. 1976. Early life history studies of American Shad in the lower Connecticut River and the effects of the Connecticut Yankee Plant. Pages 141-168 in Am Fish. Soc. Monogr. No. 1.

Martino, Edward J. 2008. Environmental controls and biological constraints on recruitment of striped bass in Chesapeake Bay. Ph.D. dissertation, University of Maryland, College Park, Md.

O'Dell, J., J. Gabor, and R. Dintamin. 1975. Survey of anadromous fish spawning areas:

Potomac River and upper Chesapeake Bay drainage. Completion Report, Project AFC-8.
Maryland Department of Natural Resources, Annapolis, Maryland.

Richardson, B.M., C.P. Stence, M.W. Baldwin, and C.P. Mason. 2007. Restoration of American
shad and Hickory Shad in Maryland's Chesapeake Bay. Maryland Department of Natural
Resources, Annapolis, MD.

Richardson, B.M. C.P. Stence, M.W. Baldwin, and C.P. Mason. 2009. Restoration of Hickory Shad in three Maryland Rivers. Maryland Department of Natural Resources. Annapolis, MD.

Richardson, B.M., C.P. Stence, M.W. Baldwin, and C.P. Mason. 2011. American Shad
restoration in three Maryland rivers. 2011 progress report to Federal Aid in Sport Fish
Restoration Act grant #F-57-R.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations.
Bull. Fish. RES. Board Can. 191:382 p.

Appendix 2. *Timeline for Maryland Department of Natural Resources Patapsco River shad and herring restoration project. Project inception is proposed to begin in 2011 with hatchery upgrades. Culture, stocking and assessment began subsequent to completion of hatchery upgrades in 2013. Progress reports will be submitted annually and a final report will summarize the restoration effort at the conclusion of the project.*

	Year 1				Year 2				Year 3				Year 4				
Activity	**W**	**S**	**S**	**F**	**W**	**S**	**S**	**F**	**W**	**S**	**S**	**F**	**W**	**S**	**S**	**F**	**W**
Pond construction																	
Well installation																	
Spawning and culture																	
Marking & stocking																	
Adult assessment																	
Larval assessment																	
Juvenile assessment																	
Laboratory work																	
Data analysis																	
Report preparation																	

Appendix 3. *Estimated costs for Maryland Department of Natural Resources Patapsco River shad and herring restoration. Project consists of hatchery upgrades and three years of culture, stocking and assessment.*

Category	**Description**	**Estimated cost**
Hatchery upgrades	Line two ponds at Manning Hatchery	$200,000
Hatchery upgrades	Install production well and water treatment equipment	$100,000
Assessment costs	Year 1, one project manager and two technicians	$100,000
Assessment costs	Year 2, one project manager and two technicians	$100,000
Assessment costs	Year 3, one project manager and two technicians	$100,000
Production costs	Year 1, chemicals, utilities, oxygen, fuel, lab supply	$50,000
Production costs	Year 2, chemicals, utilities, oxygen, fuel, lab supply	$50,000
Production costs	Year 3, chemicals, utilities, oxygen, fuel, lab supply	$50,000
Total project costs	**One year construction, three years stocking/assessment**	**$750,000**

Budget narrative and project responsibilities

Maryland DNR requests funding to perform necessary facility upgrades at Manning Hatchery in order to increase production capacity for this project. Two production ponds require renovation by installation of pond liner material. We propose to line two 0.5 acre production ponds at an estimated cost of $200,000/acre. Additionally, a new production well is required to account for additional production. Estimated cost for a 40 GPM production well, variable speed pump and required water treatment equipment is $100,000.

Funds are requested to perform larval, juvenile and adult assessment to evaluate the efficacy of the restoration project. Funds will be used to hire one project manager and two seasonal technicians. Funds will also be used to purchase equipment and supplies including nets, electrofishing parts, chemicals and laboratory necessities. Staff will perform field sampling and collections, laboratory sample preparation and evaluations, data analysis and report writing. This work will be contracted through the U.S. Fish & Wildlife Service Maryland Fishery Resources Office (USFWS-MFRO). Staff at MFRO have extensive experience in anadromous species restoration and will conduct the routine assessment work under the supervision of Steve Minkkinen, MFRO Project Leader. MDNR will oversee all assessment activities under the supervision of Chuck Stence, Anadromous Restoration Project Leader.

Funds are requested to perform brood collection, egg collection, egg culture, larval culture and juvenile culture. These funds will be used to purchase equipment and supplies including electrofishing parts, chemicals, marking supplies, oxygen, utilities, fish food, fuel, nets and hatchery equipment.

The project will be managed by Brian Richardson, MDNR Fisheries Service Hatcheries Division Manager as the Principal Investigator. Mr. Richardson will be responsible for implementation of the project including the provision of sub-contracts to co-investigators. The business aspects of the grant will be administered through the Administration and Fiscal Services Office of MDNR Fisheries Service. The business point of contact is: Carl Simon, Director of Management Services, 580 Taylor Avenue, B-2, Annapolis, MD 21401. The accounting systems used by the state are Statewide Financial Management Information Systems (FMIS/R stars), and for disbursement purposes, the Payment Management System (PMS), and the Automated Standard Application for Payments systems for use by the U.S. Department of Commerce and various other agencies.